

REVIEW OF THE AMMONIA INDUSTRY AND ITS APPLICATION TO NORTH DAKOTA

BY L. F. HEISING

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INTRODUCTION AND SUMMARY

This report is a general summary of pertinent data on the manufacture and use of synthetic ammonia products. It provides a condensed summary of the potentialities of a synthetic ammonia industry in North Dakota for Federal, State, and private organizations that may be interested in helping to develop an integrated synthetic ammonia and fertilizer industry. The report contains discussions of: (1) Materials used in the manufacture of nitrogenous fertilizers, nitric acid, and urea; (2) National production, imports, exports, and consumption; (3) the ammonia industry, location, capacity of plants; (4) processes used in manufacturing synthetic ammonia, nitric acid, and urea; (5) other potential industries; and (6) analyses of manufacturing and plant costs. Additional information on industrial compounds from ammonia and plant nutrients removed by crops is given in Appendixes 1 and 2.

Synthetic ammonia is one of the primary ingredients in fertilizers. Resources required in synthetic ammonia manufacture are available in North Dakota. Hydrogen is available from the petroleum and natural gas resources, particularly in the Williston Basin, and from the large lignite resources in the State. Hydrogen can be produced from lignite by a gasification process developed by the Bureau of Mines at Grand Forks, N. Dak.

It is estimated that the market demand and market area for a plantsite at Bismarck, N. Dak., would be adequate to sustain a 120-ton-per-day synthetic ammonia plant.

In addition to ammonia fertilizers, the plant could be integrated to produce nitric acid, explosives, and urea. Possibilities exist for developing markets for these latter products manufactured at a plantsite at Bismarck, N. Dak.

Preservation of soil fertility is an aspect of National conservation that is vital to agriculture. The uncontrolled exploitation of this resource, without replacing plant nutrients, could eventually lead to National bankruptcy.

The demands for ammonia appear to be pyramiding. The real question is whether or not there will be enough even when the industry meets the projected DPA goal. One of the basic reasons for the tremendous demand for ammonia is supplying the needed nitrogen in fertilizers. Fertilizer consumption has been growing constantly and future requirements will represent tremendous increases. Estimates of United States consumption of nitrogen as plant nutrient in 1955 are 2,300,000 tons. The growth is due to the fact that only recently has the farmer begun to realize the benefits that can be derived from the increased use of fertilizer. Department of Agriculture expects the biggest increases in fertilizer use will come from forage crops and grains, which now receive little or no

fertilizer. Increased irrigation will make available more arable land and thus increase fertilizer use. To feed the 200 million U. S. population anticipated by 1975, vast increases in the use of fertilizer will be required. Sherman E. Johnson of the Department of Agriculture recently expressed himself on the fertilizer situation, "most farmers today are not using fertilizer at the most profitable rates under present conditions." In his opinion, most of them could use more fertilizer and increase their profits even in the face of somewhat lower prices.^{2/}

ACKNOWLEDGMENTS

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PROCESS REQUIREMENTS AND RESOURCES

Process requirements for the manufacture of chemical nitrogen products are few in number. A source of nitrogen is necessary; this is available in huge quantities from the atmosphere, which, by volume, contains 79 percent of this element. Hydrogen, the other principal component of ammonia, is readily available from water gas, producer gas, coke oven gas, catalytic conversion of natural gas, and the electrolysis of water. The largest source of hydrogen is the catalytic conversion of natural gas using metallic nickel as the catalyst. This process accounts for about 70 percent of the hydrogen used in the manufacture of synthetic ammonia.

The primary product of a chemical nitrogen plant is ammonia, which is a raw material for the preparation of other nitrogenous compounds. Carbon dioxide, a waste product in the production of hydrogen, may be combined with ammonia to produce urea. An ammonia plant produces nitric acid by oxidizing the ammonia. Ammonia reacted with nitric acid yields ammonium nitrate.

^{2/} Chemical and Engineering News, CCDA Official Reviews Markets for Three DPA-Goal chemicals: Vol. 31, Mar. 30, 1953, p. 1318.

Large quantities of water are necessary in the various processes. In a large plant producing 570 tons of ammonia per day, 133 million gallons of water are circulating throughout the plant, with a daily use of about 4,297,000 gallons as process water.

About 1,500 kilowatt hours is used in manufacturing 1 ton of ammonia. Power is required for compressors, pumps, and other plant equipment. In plants in areas where natural gas is cheap, power for operation is furnished by large natural gas engines.

The process requirements for manufacturing various chemical nitrogen compounds are listed in table 1. These requirements were calculated from published data on the operation of the Lion Oil Co. chemical plant at El Dorado, Ark. This is one of the largest integrated fertilizer manufacturing plants in the country. Figures 1 and 2 give an idea of the magnitude of a plant producing 570 tons of ammonia per day.

The raw materials reserve for the manufacture of synthetic ammonia is virtually inexhaustible; the primary raw materials being atmospheric nitrogen, natural gas, coal, and water.

Nitrogen is the predominant element of the air, forming approximately four-fifths of it by volume. It has been estimated that the earth's atmosphere contains 4,000,000,000,000,000 tons of nitrogen and Bates states that the air over each square mile of the earth's surface carries 20,000,000 tons of nitrogen, a quantity sufficient to last the world for about five years at the present rate of consumption. When the surficial area of the globe, 196,950,000 square miles, is considered, the magnitude of the enormous supply can be appreciated.^{3/}

The commercial production of natural gas in North Dakota comes from wells in the southeastern extension of the Cedar Creek field of Montana. The wells are near the Montana-North Dakota boundary in southwestern Bowman County, N. Dak. The gas enters the Montana-Dakota Utilities Co. pipeline system that supplies parts of the Dakotas and eastern Montana. The present unobligated production from these wells is not adequate for a minimum 120-ton-per-day ammonia plant.

The production of commercial natural gas in North Dakota, number of wells drilled, and in production is given in table 2.

The average value of natural gas at the well during 1949 was 5.2 cents per thousand cubic feet. The average cost to industrial users was 45.3 cents per M cubic feet. In 1949 534,000,000^{4/} cubic feet of natural gas was exported from North Dakota to users in other States.

Large quantities of natural gas are at present being wasted in the new Williston Basin oil fields. In the future, as pipelines and refinery facilities are built, this gas will be available to markets. The amount of natural gas in this field is unknown. An estimate of the minimum amount of natural gas that can be expected to be available may be indicated by the fact that the Signal Oil and Gas Co. is building a natural gas processing plant near Tioga, N. Dak., reportedly of 40,000,000-cubic feet-per-day capacity. This plant will be supplied by the Beaver Lodge and Tioga oil fields.

^{3/} Johnson, B. L., Nitrogen and Its Compounds: Bureau of Mines Inf. Circ. 6385, 1931, p. 2.

^{4/} Colby, D. S., Barton, H. J., Oppegard, B. E., Natural Gas: Bureau of Mines, Minerals Yearbook preprint chapter, 1950, p. 23.

TABLE 1. - Process requirements annually at 1950 rate of national production of ammonia, nitric acid, ammonium sulfate, and ammonium nitrate^{1/}

Product	Process requirements per ton	Annual tons 1950	Process requirements per year
Sulphuric acid 98 percent	Water (process).....335 gal.	1,545,500	517,742,500 gal.
	Water (cooling).....117 gal.		180,823,500 gal.
	Sulfur.....680 lb.		525,470 tons
	Air.....85,000 cu.ft.		131,367,500 M cu.ft.
	Catalyst (vanadium pentoxide)		(3)
	Power.....30 kw.-hr. ^{2/}		46,365,000 kw.-hr.
Ammonium sulfate	Sulphuric acid.....1,500 lb.	1,968,737	1,545,500 tons
	Water (process).....115 gal.		226,405,000 gal.
	Water (cooling).....80 gal.		157,499,000 gal.
	Anhydrous ammonia.....526 lb.		517,800 tons
	Power.....26 kw.-hr. ^{2/}		51,187,162 kw.-hr.
Ammonium nitrate	Nitric acid.....1,842 lb.	1,213,911	1,118,000 lb.
	Ammonia.....989 lb.		600,280 tons
	Water (process).....7,500 gal.		9,104,332,500 gal.
	Clay conditioner.....160 lb.		97,112 tons
	Power.....40 kw.-hr.		48,556,440 kw.-hr.
Anhydrous ammonia ^{4/}	Natural gas (process)..21,000 cu.ft.	1,565,569	26,301,555 M cu.ft.
	Air.....31,000 cu.ft.		38,826,105 M cu.ft.
	Water (process).....3,288 gal.		4,118,072,040 gal.
	Water (cooling).....1,590 gal.		1,991,403,450 gal.
	Coke.....3 tons		939,340 tons
	Power.....1,500 kw.-hr.		2,348,353,500 kw.-hr.
	Catalyst (metallic nickel)		(3)
	Catalyst (metallic iron)		(3)
Nitric acid 57 percent	Natural gas (fuel).....4,066 cu.ft.	1,498,136	6,091,420 M cu.ft.
	Air.....131,000 cu.ft.		196,255,816 M cu.ft.
	Water (process).....135 gal.		2,248,360 gal.
	Water (cooling).....1,160 gal.		1,737,837,760 gal.
	Anhydrous ammonia.....600 lb.		449,440 tons
	Catalyst (platinum rhodium)0.012 oz.		17,977 oz.
	Power.....360 kw.-hr. ^{2/}		539,328,960 kw.-hr.

^{1/} Resen, F. L., Lion Chemical Produces 1,200 tons of Petro-Chemicals From Natural Gas: Oil and Gas Jour., vol. 50, June 1951, p. 77.

^{2/} Electrical World, vol. 136, Aug. 27, 1951, p. 120.

^{3/} No figure published.

^{4/} Process requirements calculated on basis of 80 percent production by natural gas reforming and 20 percent by coke gasification.

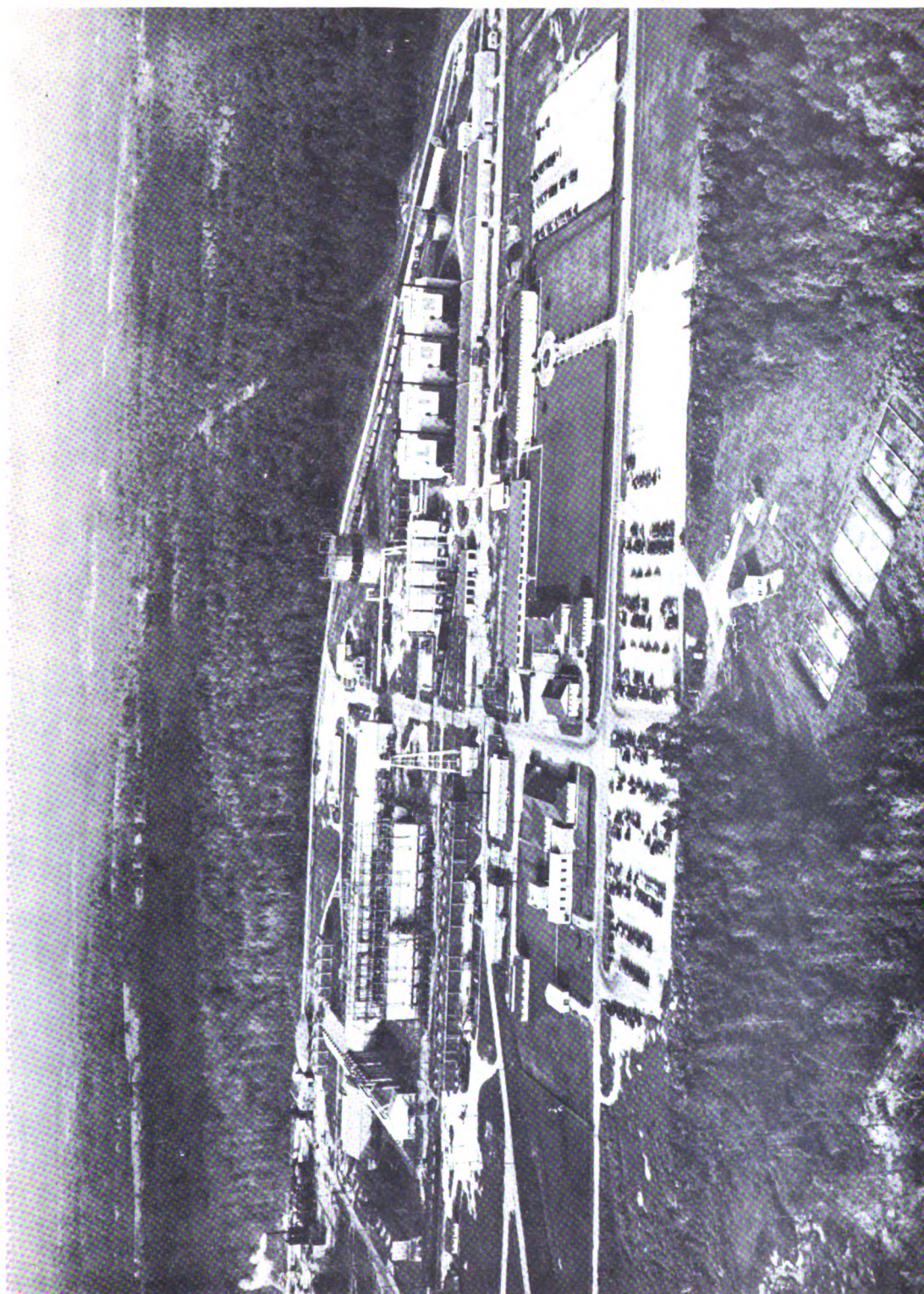


Figure 1. - Aerial view of Lion Oil Co. ammonia plant at El Dorado, Ark.
(*Photograph courtesy of Lion Oil Co.*)

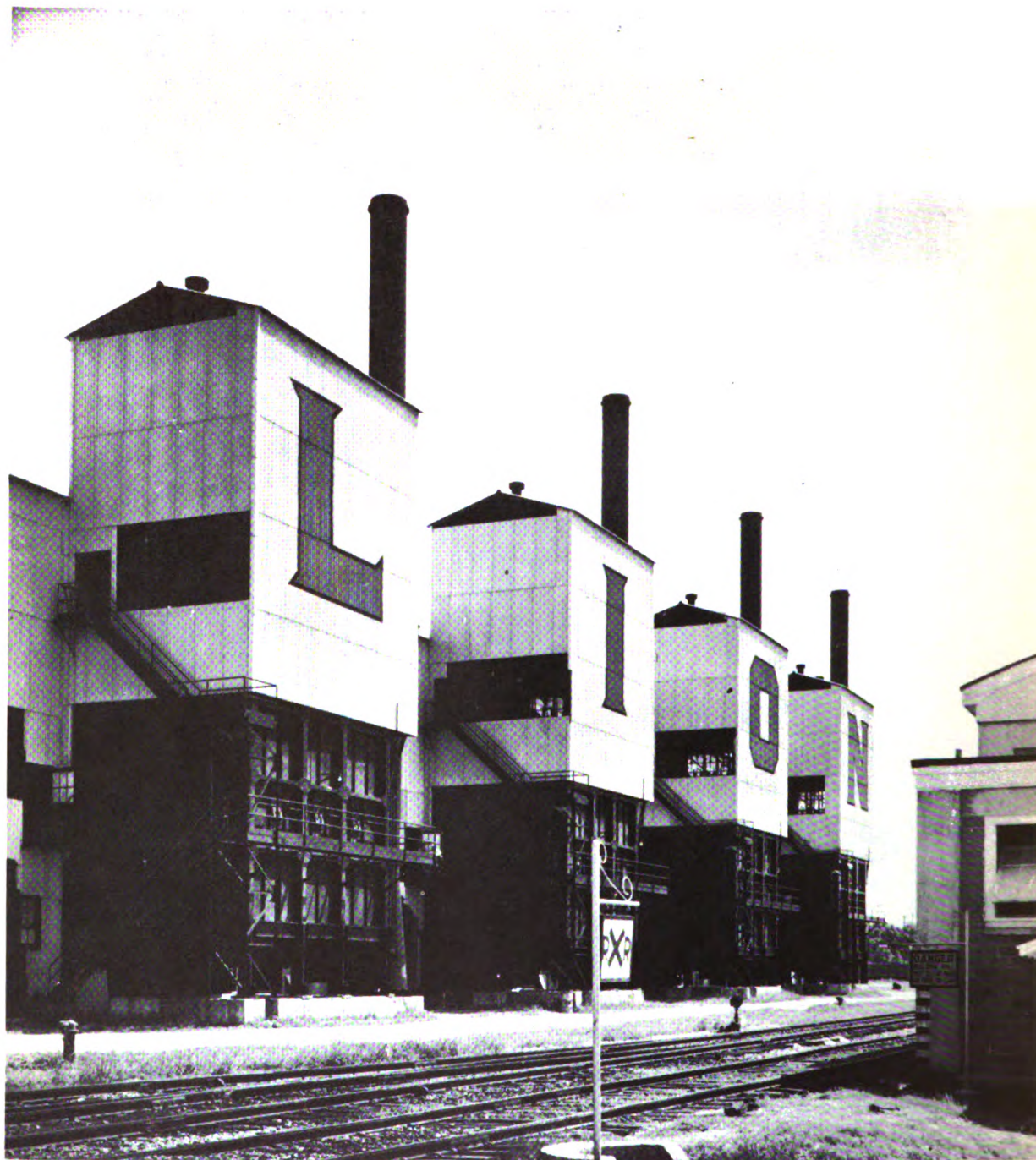


Figure 2. - Primary reform furnaces, Lion Oil Co. ammonia plant, El Dorado, Ark.
(Photograph by Edward M. Payne, courtesy of Lion Oil Co.)

TABLE 2. - Production of Commercial Natural Gas in North Dakota

Year	Wells drilled	Wells in production	Production, cubic feet
1929			21,518,000
1930-37			None
1938			78,005,000
1939		3	77,676,000
1940	5	8	None
1941			116,165,000
1942		8	121,055,000
1943		7	177,067,000
1944		4	200,105,000
1945		13	216,773,000
1946	15	12	313,930,000
1947		25	442,213,000
1948		25	642,687,000
1949	1	26	528,548,000
1950		26	608,021,608
1951		28	463,000,000
1952		?	?

Note: Production figures compiled by North Dakota Research Foundation.

Lignite deposits of North Dakota amount to approximately 16 percent of the coal resources of the United States. Recent estimates of the Federal Geological Survey indicate recoverable reserves of 175 billion tons of lignite in North Dakota.^{2/}

Lignite is characterized by a high moisture content, averaging about 37 percent; a heating value of approximately 6,800 B.t.u. per pound; a moderate ash content of about 6 to 7 percent; and a sulfur content, averaging approximately 0.6 of 1 percent.

The water supply in the streams throughout the region of the coal resources of North Dakota varies greatly. Figure 3 indicates the water resources of North Dakota with relation to the coal-producing areas.

USES OF AMMONIA

The main use for ammonia is for fertilizer manufacture in the form of ammonium nitrate, ammonium sulfate, ammoniated super-phosphates, and urea. It serves as a raw material for manufacturing nitric acid, which is transformed into sodium nitrate or ammonium nitrate. Anhydrous ammonia is also an important refrigerating agent, because of its low cost and high thermodynamic efficiency. Other uses for ammonia are as a water purification agent and as a nitriding agent for steel.

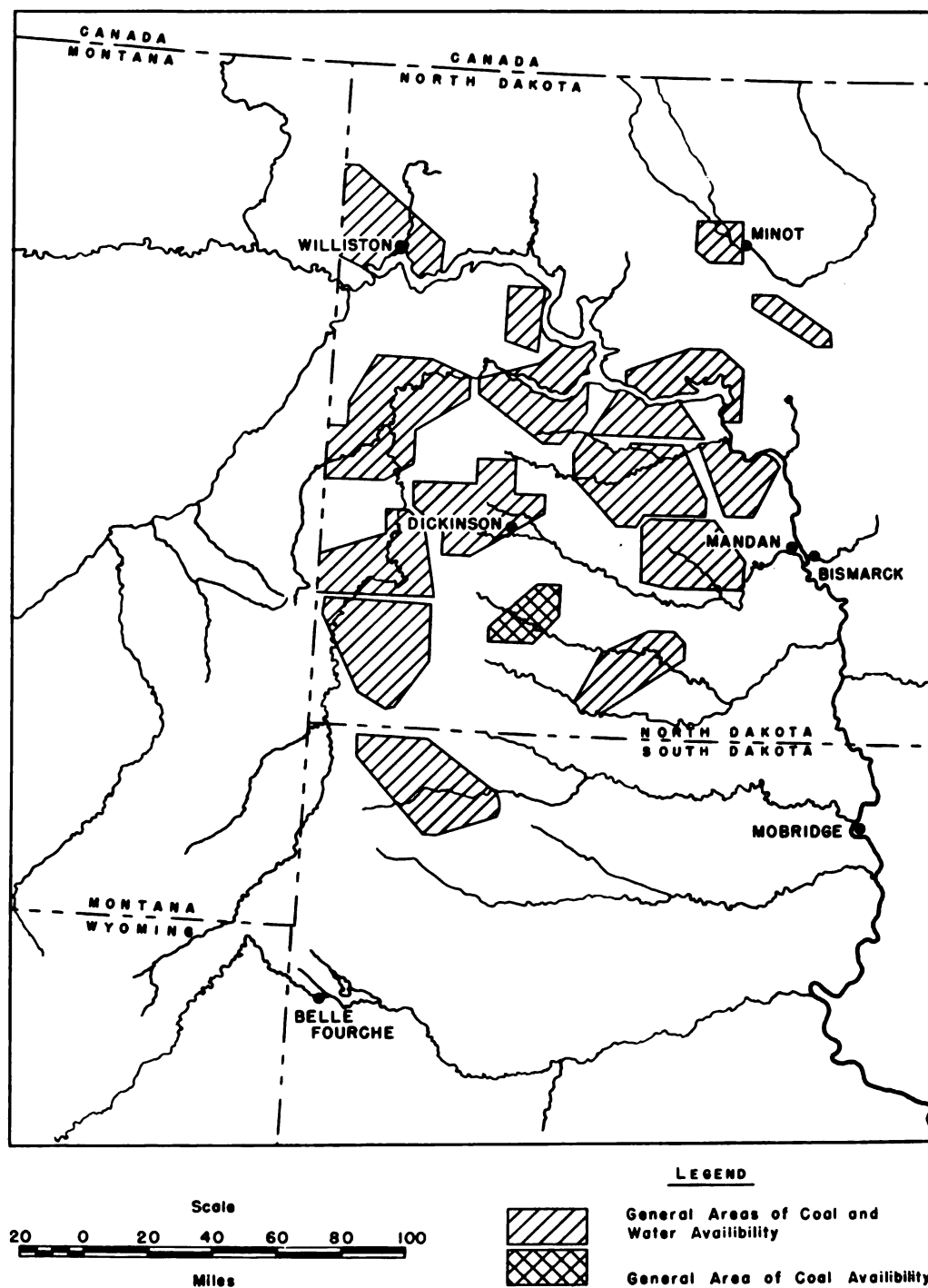
Anhydrous ammonia and aqua ammonia are applied directly to the soil as a fertilizer. In the 1951-52 agricultural year, 204,000 tons of ammonia were applied in this manner.

^{2/} Brant, R. A., Lignite Resources of North Dakota: Geol. Survey Circ. 226, 1953, p. 8.

Source: Ford, Bacon & Davis , The Synthetic Liquid Fuel Potential

August 10, 1951

Of North Dakota And South Dakota



APRIL 13, 1953

Figure 3. - Water resources of North Dakota in relation to coal-producing areas.

Nitric acid is an important intermediary chemical in the production of other substances. It is used in the nitration of various organic compounds. The nitration of the hydrocarbons resulting from the destructive distillation of coal tar (benzene, naphthalene, and anthracene) yields the bases for a wide assortment of dyes. Nitrobenzene is a basic chemical in the aniline dye industry. The nitrated products of the benzene series (benzene, toluene, and phenol) also furnish important explosives, such as trinitrobenzene, trinitrotoluene (TNT), and picric acid. The nitration of cellulose yields nitrocellulose, which is used in making smokeless powders, gelatin dynamites, collodion, rayon, lacquers, enamels, varnishes, and bronzing liquids. The nitration of glycerin yields nitroglycerin, the base for ordinary dynamite.

Ammonium sulfate is used as a fertilizer and for fireproofing fabrics.

Urea is used as an animal feed; it is also a highly concentrated nitrogen fertilizer. Urea also is used in the manufacture of important plastics, such as urea-formaldehyde and urea-furfural resins, and in plastic wood. Dimethylol urea is used in transmuted wood.

NATIONAL PRODUCTION

Synthetic Ammonia

The United States is the largest producer and consumer of nitrogen compounds in the world. Since its beginning in 1921, the chemical nitrogen industry in the United States has become a giant with a proposed annual production of 2,900,000 tons.

Between 1921 and 1931, 11 synthetic ammonia plants were built in the United States. One plant was abandoned later; but in 1934 the combined production capacity of the other 10 was 344,000 tons of nitrogen annually. This capacity remained the same until the beginning of World War II.

In the spring of 1940, a new era of development of synthetic ammonia facilities began. Most of the old plants were enlarged and 10 new ones were built. This development occurred in the 3 years from 1941 to 1943, inclusive.

After World War II, the synthetic ammonia plants built by the Government during the war years with the exception of the Muscle Shoals plant, Ala., were sold or leased to private operators. In many cases they were the same companies that operated the plants for the Government during the war.

A new era of construction of synthetic ammonia plants began after World War II. The proposed expansion to be completed by 1955 is expected to increase the annual capacity of the United States to fix atmospheric nitrogen to 2,930,000 tons. A list of these proposed plants is given in table 3. To facilitate the proposed expansion, and to make more attractive the investment of capital in these plants, the Government has provided for accelerated amortization with tax benefits.

Production of nitrogen compounds is increasing each year as new plants enter production. Statistics of recent production are given in table 4.

TABLE 3. - Synthetic ammonia plants being built or planned under 1955 expansion program^{1/2/}

Company	Location	Capital cost	Estimated completion date	Remarks
Allied Chem. & Dye Corp. Do.	South Point, Ohio	\$ 7,270,000	July '53	Addition to present plant.
American Cyanamid Co.	La Platte, Neb.	24,600,000	Spring '54	Urea, natural gas.
Ammonia Chem. Corp.	New Orleans, La.	53,735,000	Dec. '54	Urea.
Atlantic Refining Co.	Aleander, Calif.	-	-	-
Brea Chemicals, Inc. (Union Oil)	Philadelphia, Pa.	3,400,000	Sept. '53	Natural gas.
Cities Service Oil Co.	Brea, Calif.	13,000,000	July '54	-
Commercial Solvents Corp.	Lake Charles, La.	28,391,000	-	-
Coop. Farm Assoc.	Sterlington, La.	20,537,800	July '53	Natural gas-addition to present plant.
Delta Chem. Co.	Lawrence, Kan.	13,818,000	-	-
Diamond Alkali Co.	Buras, La.	8,892,000	Oct. '53	-
Dow Chem. Co.	Houston, Tex.	1,606,000	-	Application withdrawn.
Fitrol Corp.	Freeport, Tex.	4,316,800	-	Addition to present plant.
Food Mach. & Chem. Corp.	Vernon, Calif.	3,716,000	-	-
Grace Chem. Co.	West Virginia	2,503,000	-	Indefinite.
Gulf States Utilities Co.	Woodstock, Tenn.	15,466,000	Jan. '54	250 tons/day natural gas, ammonia.
John Deere & Co.	Beaumont, Tex.	16,500,000	-	-
Lion Oil Co.	Pryor, Okla.	18,500,000	Jan. '54	180 tons/day urea.
Mill Creek Chem. Corp.	Luling, La.	30,516,000	-	300 tons/day natural gas, ammonia, ammonium nitrate.
National Chem. Corp.	Salt Lake City, Utah	-	-	186 tons/day ammonia.
National Distillers Products Corp.	Yazoo City, Miss.	7,212,446	-	-
Northern Chem. Industries	Tuscola, Ill.	7,000,000	-	50,000 tons ammonia/year.
Pacific Chem. Co.	Sandy Point, Maine	8,700,000	-	-
Penn. Salt Mfg. Co.	Pasco, Washington	5,735,000	Oct. '53	-
Phillips Chem. Co.	Wyandotte, Mich.	2,400,000	June '53	Addition to present plant.
Shell Chem. Corp.	Port Adams, Tex.	38,760,000	Nov. '53	-
Sid Richardson Gasoline Co.	Dominguez, Calif.	7,600,000	May '53	Natural gas.
Spencer Chem. Co.	Pointe a la Hache, La.	19,000,000	Dec. '54	-
Do.	Vicksburg, Miss.	13,958,000	April '53	-
United States Government	Pittsburg, Kan.	13,758,000	-	25 percent complete.
Wyandotte Chem. Co.	De Soto, Kan.	2,200,000	-	New Daniels process for the direct oxidation of atmospheric nitrogen.
	Wyandotte, Mich.	2,624,000	-	-

^{1/} National Production Authority Release 2382, July 2, 1952.

^{2/} Applicants for tax certificates for accelerated amortization.

TABLE 4. - Principal nitrogen compounds produced in the
United States, 1943-50, in short tons^{1/}

Compounds	1943	1944	1945	1946
Ammonia (NH₃):				
Synthetic plants:				
Anhydrous ammonia.....	543,804	543,651	548,655	725,537
Byproduct coking plants (NH ₃ content):				
Aqua ammonia.....	34,106	31,605	27,607	24,991
Ammonium sulfate.....	190,317	204,561	191,073	160,938
NH ₃ equivalent all forms.....	224,423	236,226		
Total ammonia.....	992,650	1,016,043	767,335	911,466
Ammonium sulfate:				
Synthetic plants.....	65,000	88,000		156,653
Byproduct coking plants.....	761,270	818,244	764,293	643,752
Total.....				
Ammonium nitrate, basis solution 100 percent NH ₄ NO ₃				724,899
Compounds	1947	1948	1949	1950
Ammonia (NH₃):				
Synthetic plants:				
Anhydrous ammonia.....	1,114,000	1,089,786	1,294,057	1,565,569
Byproduct coking plants (NH ₃ content):				
Aqua ammonia.....	25,718	24,753	22,750	23,387
Ammonium sulfate.....	202,360	207,671	189,202	207,754
NH ₃ equivalent all forms.....				
Total ammonia.....	1,342,078	1,322,210	1,506,009	1,796,710
Ammonium sulfate:				
Synthetic plants.....	195,848	264,476	846,195	1,137,721
Byproduct coking plants.....	809,440	830,683	756,807	831,016
Total.....				1,968,737
Ammonium nitrate, basis solution 100 percent NH ₄ NO ₃	1,086,869	988,342	1,018,706	1,213,911

^{1/} Bureau of Mines Minerals Yearbook

Byproduct Ammonia

Production of byproduct ammonia depends on the production of coke. The largest commercial user of coke is the steel industry. In years of large steel production a large quantity of byproduct ammonium sulfate is produced. The average yield of ammonium sulfate per ton of coal charged to the coke oven is 20 pounds. Eighty-one plants in 21 States produced 251,141 tons of byproduct ammonia in 1950.

Nitric Acid

Production of nitric acid has been steadily increasing since 1935. In 1935, the total production was 96,109 tons. Present production is 16 times this amount. In 1951 a production of 1,512,609 tons was achieved. There are 28 nitric acid plants in the country. Nitric acid plants are, in most cases, integrated with synthetic ammonia plants. The 10 synthetic ammonia plants built by the Government during World War II have integrated nitric acid plants. Statistics on the production of nitric acid in the United States, since 1935, are given in table 5.

TABLE 5. - Production of nitric acid in the United States,
1935-52^{1/}

Year	Short tons	Year	Short tons
1935	96,109	1947	1,190,060
1937	175,860	1949	1,129,521
1939	167,740	1950	1,335,718
1941	347,360	1951	1,512,609
1943	485,248	1952	2,053,787
1945	447,008		

^{1/} Preliminary, Bureau of Census, Facts for Industry Series M-19A

CONSUMPTION, PRICES, IMPORTS, AND EXPORTS

Domestic utilization of chemical nitrogen may be classified as in fertilizers, in industry (other than explosives), and in explosives.

Fertilizers

The major use of synthetic ammonia in the United States is in the manufacture of fertilizers. About 60 percent of the annual synthetic ammonia production is used for this purpose. The use of nitrogen fertilizer has increased more than three-fold during the last decade. New nitrogen plants are being planned or are under construction to meet the continuing growing demand for this type of fertilizer.

Sales of nitrogen fertilizer in 1910 were more than twice as great as in 1900, and in 1920 were nearly 60 percent higher than in 1910. Consumption increased each year until 1930, after a drop during 1930-32, consumption increased gradually until the beginning of World War II. A shortage of nitrogen developed in 1942, owing to the increased demand for it in the manufacture of munitions. In spite of these war demands, however, the consumption of nitrogen as a fertilizer continued to increase rapidly. An all time record of 1,238,234 tons of nitrogen for fertilizer use was established in 1951, table 6. The 1930 figures may be taken as the last normal figures before the depression and the 1935-39 average as about normal for the pre-war period.

TABLE 6. - Apparent consumption of fertilizer nitrogen for United States agriculture, in short tons, 1930-52^{1/2/3/}

Year	Tons	Year	Tons
1930	342,000	1941	445,000
1931	273,000	1942	379,000
1932	194,000	1943	497,000
1933	220,000	1944	618,000
1934	259,000	1945	668,000
1935	306,000	1946	734,000
1936	342,000	1947	824,482
1937	402,000	1948	856,719
1938	372,000	1949	919,946
1939	384,000	1950	1,005,000
1940	428,000	1951	1,238,234
		1952	1,350,000 ^{4/}

^{1/} Includes Hawaii, Puerto Rico, and Government distributed fertilizer.

^{2/} Data 1930-35, inclusive, Chemical Nitrogen; U. S. Tariff Comm. Rept. No. 114, 2d Sec. p. 188, 1937.

^{3/} Mehring, A. L., and Clark, K. G., Production, Consumption, Foreign Trade of Plant Food in U. S : Agr. Chem., vol. 6, February 1951, p. 38.

^{4/} Estimated.

Industry (other than explosives)

About 30 percent of the total synthetic ammonia production is consumed by industries other than the explosives industry. The largest consumers are: Plastics, textiles, industrial chemicals, the petroleum industry, and refrigeration. End-use patterns of synthetic ammonia for 1941 and estimates for 1949 are given in table 7. Increased output of plastics and synthetic textiles will increase the use of ammonia in these industries.

Explosives

Except during war years, about 10 percent of the synthetic ammonia production is consumed in explosives. Consumption during wartime has been directed, to a large extent, into the manufacture of nitric acid for use in the manufacture of military explosives, such as gun cotton, TNT, and ammonium nitrate. The explosives used for peace-time purposes, the industrial explosives, are chiefly dynamite, black powder, and mixed explosives, such as the ammonium nitrate mixtures.

Prices

Although nitrogenous compounds are valued, in most cases, for the nitrogen they contain, they are not sold on the basis of their nitrogen content. In the United States there are no officially recognized quotations. The quotations that appear in trade journals are designed to represent spot prices in principal markets. Large consumers buy directly from chemical plants on contract. Contract prices are, in general, lower than quoted spot prices. The average annual prices of the principal nitrogen compounds since the beginning of the present century are given in table 8. The price of nitric acid, 42° B., has remained constant at 6.5 cents per pound since 1929.

TABLE 7. - Synthetic ammonia end-use pattern, short tons^{1/}

Use	1941	1949 ^{2/}
Industrial:		
Industrial explosives.....	73,740	120,000
Soda ash.....	300	3,000
Sulfuric and nitric acids.....	33,680	58,000
Petroleum refining.....	6,630	13,000
Refrigeration.....	13,560	18,000
Fermentation (yeast, etc.).....	1,970	3,000
Metallurgy (nitriding, etc.).....	9,410	18,000
Textiles (rayon, nylon, etc.).....	10,670	31,000
Rubber (accelerators).....	2,000	5,000
Plastics, resins, finishes.....	24,400	90,000
Dyes and intermediates.....	11,520	20,000
Pigments and dry colors.....	810	3,000
Ammonium salts.....	14,800	20,000
Nitrates and nitrites.....	8,250	25,000
Amines, amides, cyanamides.....	7,340	35,000
Water treatment.....	-	20,000
Other industrial uses.....	28,300	18,000
Sub-total.....	247,380	500,000
Less conversion losses (7%).....		35,000
Total industrial.....	247,380	465,000
Fertilizer:		
Fertilizer solutions and ammoniation.....	92,640	316,000
Sodium nitrate.....	79,100	42,500
Ammonium nitrate.....	-	158,000
Ammonium sulfate.....	14,760	69,300
Direct application.....	7,420	54,700
Ammonium phosphate - Uramon-cal-nitro.....	-	62,000
Sub-total.....	194,320	702,500
Grand total (industrial and fertilizer).....	441,700	1,167,500

^{1/} Cope, W. C., Ammonia: Part II Cost of Production and End-Use Pattern: Chem. Ind., vol. 65, No. 1, July 1949, pp. 53-56.

^{2/} Estimated.

Imports and Exports

The United States is both a large importer and² exporter of nitrogen compounds. Large amounts of natural sodium nitrate from Chile enter the United States each year, the quantity greatly exceeding the import tonnage of any nitrogenous material. Domestic demand for Chilean sodium nitrate as indicated by the imports (see table 9) has declined since 1948; but has not yet reached the levels of 1946-47. The value of these imports dropped in 1950 to \$22,387,123. The major exporter of nitrogenous compounds to the United States is Chile. Statistics regarding the export-import trade of the United States in nitrogen compounds are given in table 9.

TABLE 8. - Average wholesale prices per unit of 20 pounds of nitrogen in various materials at producing points or ports in bulk carload lots^{1/2/}

Year	Ammonium sulfate	Anhydrous ammonia	Calcium cyanamide	Solutions average ^{3/}	Urea 42 percent	Natural organics ^{4/}
1900	\$2.79					\$2.57
1905	3.01					2.88
1910	2.64		\$3.43			3.63
1915	3.09		2.54			3.54
1920	4.08		3.40			8.71
1925	2.65		2.20			4.88
1926	2.52	\$1.75	2.19			4.62
1927	2.33	1.63	1.95			5.25
1928	2.27	1.54	2.01			6.13
1929	2.01	1.46	1.90			5.22
1930	1.79	1.40	1.65			4.50
1931	1.34	1.36	1.38			2.90
1932	1.02	1.34	1.08			1.83
1933	1.12	1.15	1.13	\$1.06		2.64
1934	1.18	1.09	1.20	1.02		3.41
1935	1.13	1.09	1.20	1.07		3.38
1936	1.17	1.09	1.21	1.05		3.52
1937	1.32	1.09	1.26	1.17	\$1.52	4.49
1938	1.36	1.09	1.29	1.22	1.37	3.52
1939	1.33	1.09	1.16	1.22	1.34	3.72
1940	1.37	1.09	1.20	1.22	1.32	3.55
1941	1.41	1.09	1.22	1.22	1.32	4.05
1942	1.43	1.09	1.44	1.22	1.37	4.70
1943	1.42	1.09	1.44	1.22	1.37	4.82
1944	1.42	.91	1.44	1.11	1.37	4.82
1945	1.42	.72	1.44	1.07	1.37	4.85
1946	1.44	.72	1.64	1.04	1.37	7.11
1947	1.60	.72	1.98	1.03	1.39	9.71
1948	2.03	.80	2.56	1.14	1.80	8.93
1949	2.29	.94	2.82	1.23	2.01	8.45
1950	1.99	.90	2.26	1.20	1.94	8.60
1951	1.83	.96	2.62	1.20	2.03	4.10
1952	1.90	.97	3.13	1.20	2.19	4.90
1953 (1st month)	2.09	.96	3.03	1.23	2.19	5.00

1/ Mehring, A. L., and Bennett, C. A., Price Relationships of Certain Nitrogen Fertilizer Materials: Agr. Chem., vol. 6, February 1951, p. 49.

2/ Computed largely from published quotations in Oil, Paint and Drug Reporter.

3/ Nitrogen solutions and urea - ammonia liquor.

4/ 1900-32, inclusive, fish scrap, animal tankage, dried blood, cotton seed meal. 1933-53 Castor pomace, process tankage, fish scrap, cotton seed meal and animal tankage.

TABLE 9. - Major nitrogen compounds imported and exported from the United States
1943-50, in short tons^{1/}

Compounds	1943	1944	1945	1946	1947	1948	1949	1950
Imports:								
Industrial chemicals:								
Ammonium nitrate.....	53,256				27	80	1	
Anhydrous ammonia.....	5,863		4	7		209		
Fertilizer materials:								
Ammonium nitrate mixtures:								
Containing less than 20 percent nitrogen.....					92	250	2,290	1,523
Containing 20 percent or more nitrogen.....								
Ammonium phosphates.....	2,895	317	655	1,105	99,322	100,314	136,405	221,299
Ammonium sulfate.....	43,987	91,943	92,757	91,113	105,189	108,228	126,274	107,695
Calcium nitrate.....	99,827	103,628	118,890	101,558	114,398	105,887	105,498	144,732
Calcium cyanamide.....	-	5	-	3,300	8,848	9,761	38,611	44,331
Nitrogenous materials, n.s.p.f.....	125,634	101,886	141,057	163,093	153,764	116,504	115,885	97,725
Potassium nitrate, crude.....	63,372	112,616	135,010	126,029	9,687	5,304	4,829	23,830
Sodium nitrate.....	761,165	713,004	849,888	540,870	556,525	709,573	675,543	618,018
Sodium-potassium nitrate.....	19,767	9,407		4,400	2,500		6,802	20,409
Exports:								
Industrial chemicals:								
Anhydrous ammonia.....	1,983	3,623	4,312	6,159	6,062	3,407	3,477	10,202
Ammonium nitrate.....	9,534	13,454	9,845	6,972	6,685	5,087	17,004	3,336
Aqua ammonia.....	6,812	2,499	2,715	(2)	(2)	(2)		
Fertilizer materials:								
Ammonium nitrate.....				(2)	(2)	(2)	470,443	94,169
Ammonium sulfate.....	78,005	10,615	20,752	25,256	88,601	136,648	660,773	819,285
Nitrogenous chemical materials, n.e.s.	13,215	11,175	83,974	117,315	153,607	701,450	23,510	41,363
Sodium nitrate.....	6,740	11,597	12,229	16,240	19,920	17,100	3,714	32,862

^{1/} Bureau of Mines, Minerals Yearbook.^{2/} Included in Nitrogenous Chemical materials n.e.s.

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Nationally

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In response to questions by NPA as to whether the present 2,930,000-ton nitrogen production goal set for 1955 is sufficient to meet requirements in all areas, individual members of the Nitrogen Industry Advisory Committee presented varying opinions, as follows:^{6/}

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(3) A near term shortage of direct application liquid ammonia is expected in the Gulf Coast areas because demand for this type of nitrogen fertilizer material is increasing and is expected to expand beyond previous estimates.

(4) Ample ammonia, however, will be available in the Gulf Coast, South, and Southeast areas when new facilities come into production.

The latest annual figures on the proposed expansion of the chemical nitrogen industry are given in table 10.

TABLE 10. - Proposed expansion of chemical nitrogen industry^{1/}

	Tons
Annual nitrogen total requirements ^{2/}	2,930,000
Present annual plant capacity	1,639,000
Amount of expansion	1,291,000
Amount of expansion unfilled	152,000

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^{2/} Estimated needs of defense program; not actual needs of agriculture alone.

Further large expansion of nitrogen production is being urged by the Department of Agriculture.^{7/} "The Department's argument is that 1 ton of nitrogen is equal to 1,400 acres of land and in any real emergency involving food shortages, this expanded production of nitrogen could be readily absorbed by agriculture."

Nitrogen requirements for agriculture in 1955 have been estimated by the Department of Agriculture. These estimates indicate future requirements of nitrogen in short tons to be almost double present use. (See fig. 4.)

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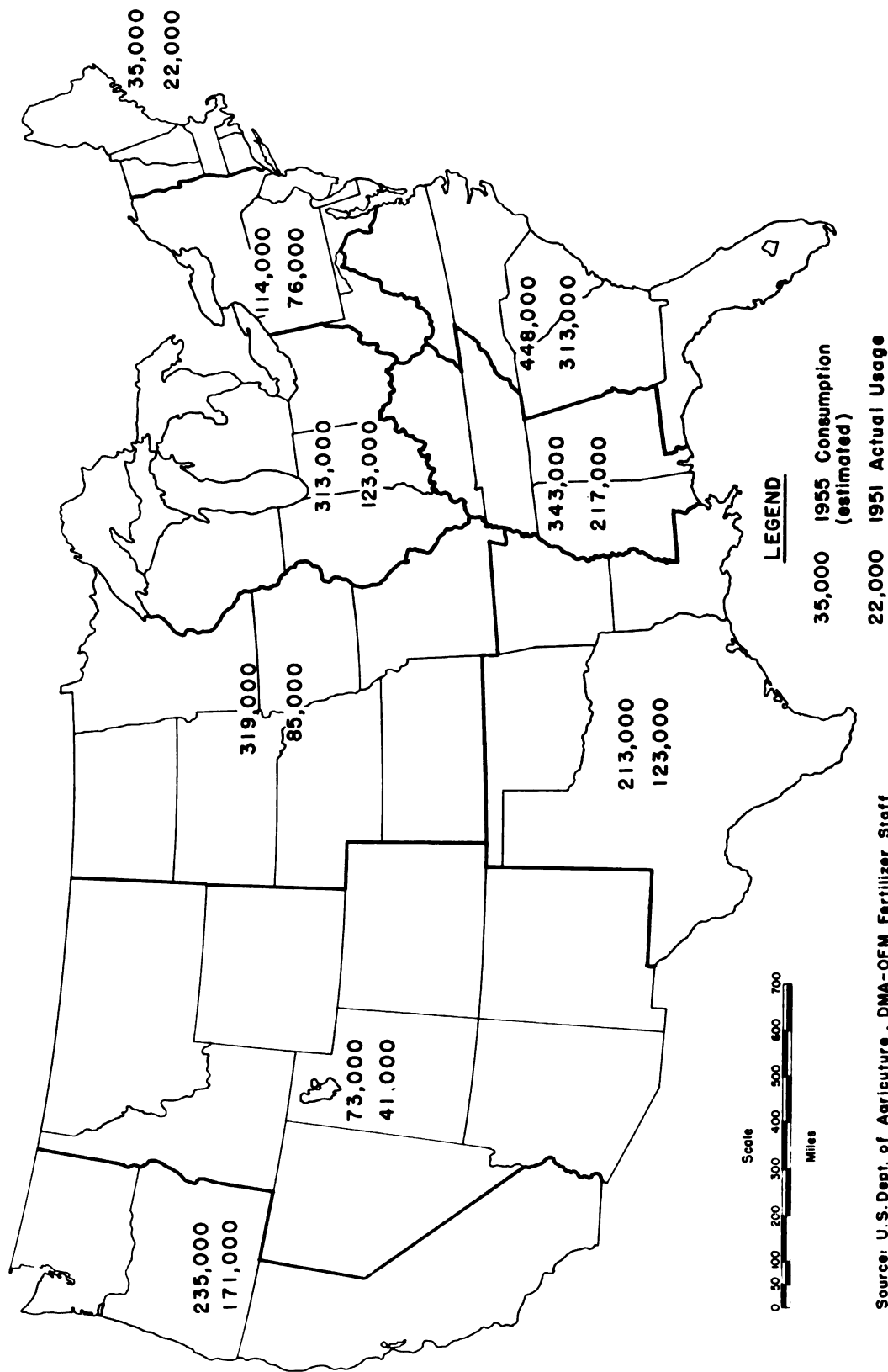


Figure 4. - Future nitrogen fertilizer consumption.

A balance sheet for United States agriculture based on the nitrogen lost from the soil each year has been calculated by Lipman, and is given in table 11.

TABLE 11. - Nitrogen: Balance sheet for United States^{1/}

	Short tons of Nitrogen
Annual losses (crops, grazing, erosion, and leaching).....	22,899,046
Annual additions (fertilizer, rain, seeds, manures, etc.).....	16,253,862
Net annual loss.....	6,645,184

^{1/} Lipman, J. G., in collaboration with Conybeare, A. B., Preliminary Note on the Inventory and Balance Sheet of Plant Nutrients in the United States: New Jersey Agr. Exp. Sta. Bull. 607, 1936, p. 20.

West North Central States

There is one chemical nitrogen plant in the West North Central States. Three plants are in the planning stage. Applications for tax certificates for accelerated amortization have been approved for these plants. A list of the proposed plants is given in table 12.

TABLE 12. - Proposed chemical nitrogen plants in the
West North Central States

Company	Location	Capital cost	Product
Allied Chem. & Dye Corp.....	La Platte, Nebr.	\$24,600,000	Urea
Coop. Farm Association	Lawrence, Kans.	13,818,000	-
Spencer Chemical Co.	Pittsburgh, Kans.	13,758,000	-

The plant at Pittsburgh, Kans., is reported as 25 percent complete. Completion date for the La Platte, Nebr., plant is given as spring of 1954. The plant at Lawrence, Kans., is still in the financing stage, and no completion date has been announced. Allied Chemical & Dye Corp. operates 2 plants outside the West North Central States, with an annual production of 455,000 tons. The Cooperative Farm Association is, in part, attempting to sell shares to farmer consumers. This system of having the farmers own their own plant has been successful in other parts of the country. The Mississippi Chemical Corp., Yazoo City, Miss., was financed in this manner.

The estimated capacity of the 2 new plants under construction in the West North Central States is 120,000 tons nitrogen annually. The nitrogen supply status in these States in 1955, if these 2 plants enter full production, is shown in table 13, and figure 4.

TABLE 13. - Estimated nitrogen fertilizer requirements -
West North Central States

Estimated requirements	Proposed production	Deficiency of production
319,000 tons ^{1/}	120,000 tons	199,000 tons

^{1/} United States Department of Agriculture.

Future needs for nitrogen fertilizer compounds in the West North Central States are expected to be much larger than the present consumption, figure 4 and table 14. In some areas of the region the use of large quantities of fertilizers is just beginning, and in other areas their use is quite limited. In North and South Dakota the indicated average amount of nitrogen fertilizer used per crop acre in 1951 was only 0.05 pounds and 0.07 pounds, respectively. Of the West North Central States, Missouri used the most, 4.8 pounds per crop acre.

Lowered transportation costs resulting from plants locating in the West North Central States will stimulate the use of more nitrogen fertilizer in the region. In addition to nitrogen fertilizers, an integrated plant could produce explosives, nitric acid, and urea. A market for explosives from such a plant may develop in the Minnesota taconite industry. Operation plans for a greatly increased mine output in this industry are underway.

TABLE 14. - Nitrogen consumption in the west North Central States
fiscal year 1951

State	Farm income, ^{1/} millions dollars 1951	Total crop ^{1/} acreage 1951, 1,000 acres	Nitrogen ^{2/} consumed, short tons	Pounds per crop acre
Minnesota.....	1,384.7	19,476	7,312	0.75
Iowa.....	2,410.9	21,861	20,302	1.9
Missouri.....	1,223.7	12,326	29,536	4.8
N. Dakota.....	656.8	21,662	573	.05
S. Dakota.....	675.3	17,801	621	.07
Nebraska.....	1,106.1	19,537	11,824	1.2
Kansas.....	1,044.0	19,632	14,798	1.5

^{1/} Crop Reporting Board, Crop Production: Bureau of Agric. Eco., Ann. Survey Issue, 1951.

^{2/} Scholl, W., and Wallace, H. M., Consumption of Commercial Fertilizers in U. S. 1950-1951: Agr. Chem., vol. 7, June 1952, p. 40.

THE AMMONIA INDUSTRY

Plant Locations

The synthetic ammonia plants of the United States are located in areas close to supplies of natural gas and coal. Older plants were located in coal-producing areas, and newer plants are located in natural gas areas. Construction of natural gas pipelines has made large quantities of natural gas available in many parts of the country. Synthetic ammonia plants now being built, in farming areas, obtain natural gas from these pipelines and have the added advantage of being close to consuming areas. The domestic areas where major nitrogen compounds are produced are indicated in figure 5. A list of synthetic ammonia plants to accompany figure 5 is given in table 15.

Plants producing ammonium sulfate use byproduct ammonia obtained from coking operations. These coke plants are usually located in areas adjacent to the steel industry: 81 plants in 21 States produced 831,016 tons of ammonium sulfate in 1950. Figure 6 shows the location of these byproduct ammonia plants.

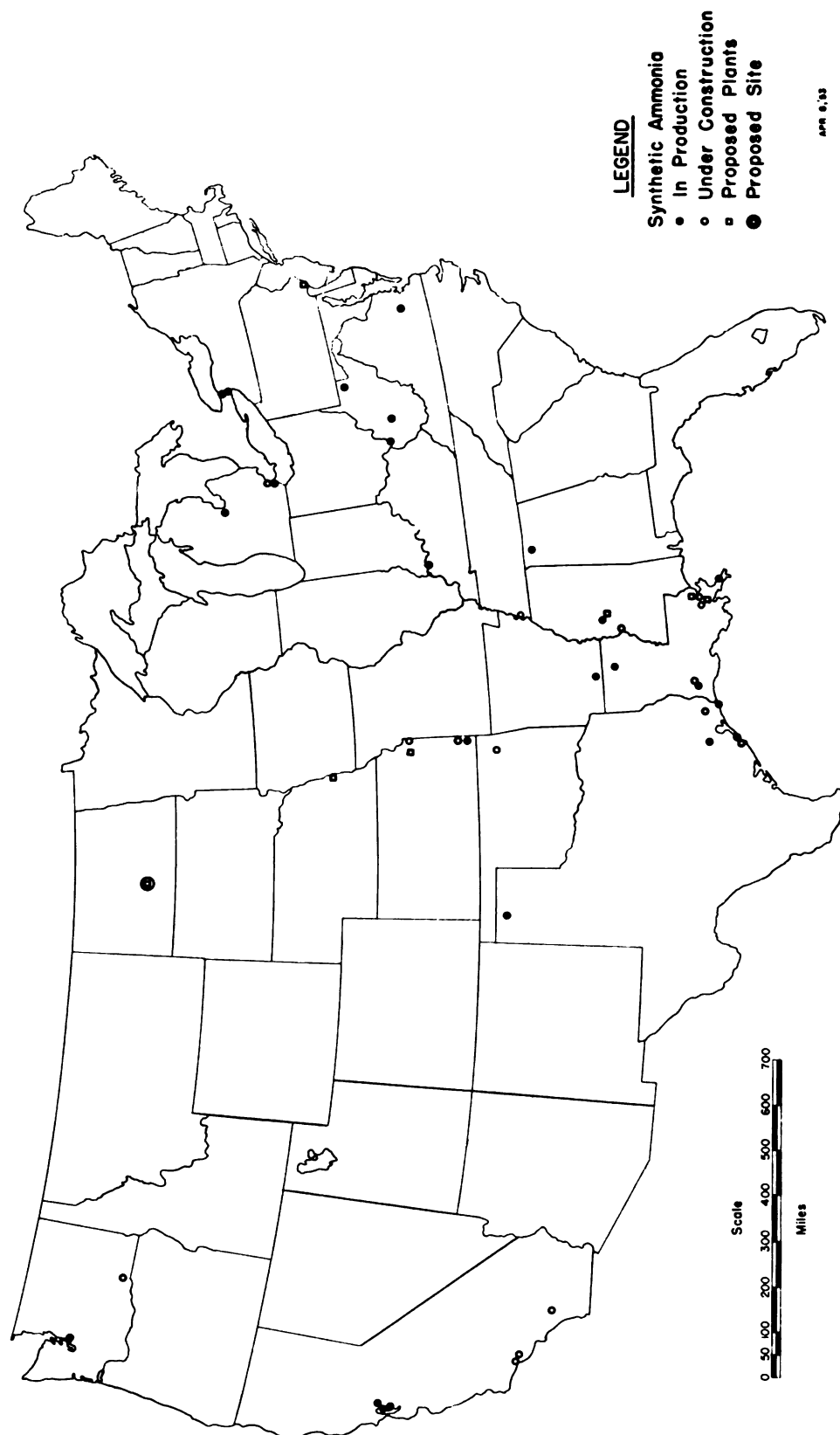


Figure 5. - Domestic areas where major nitrogen compounds are produced.

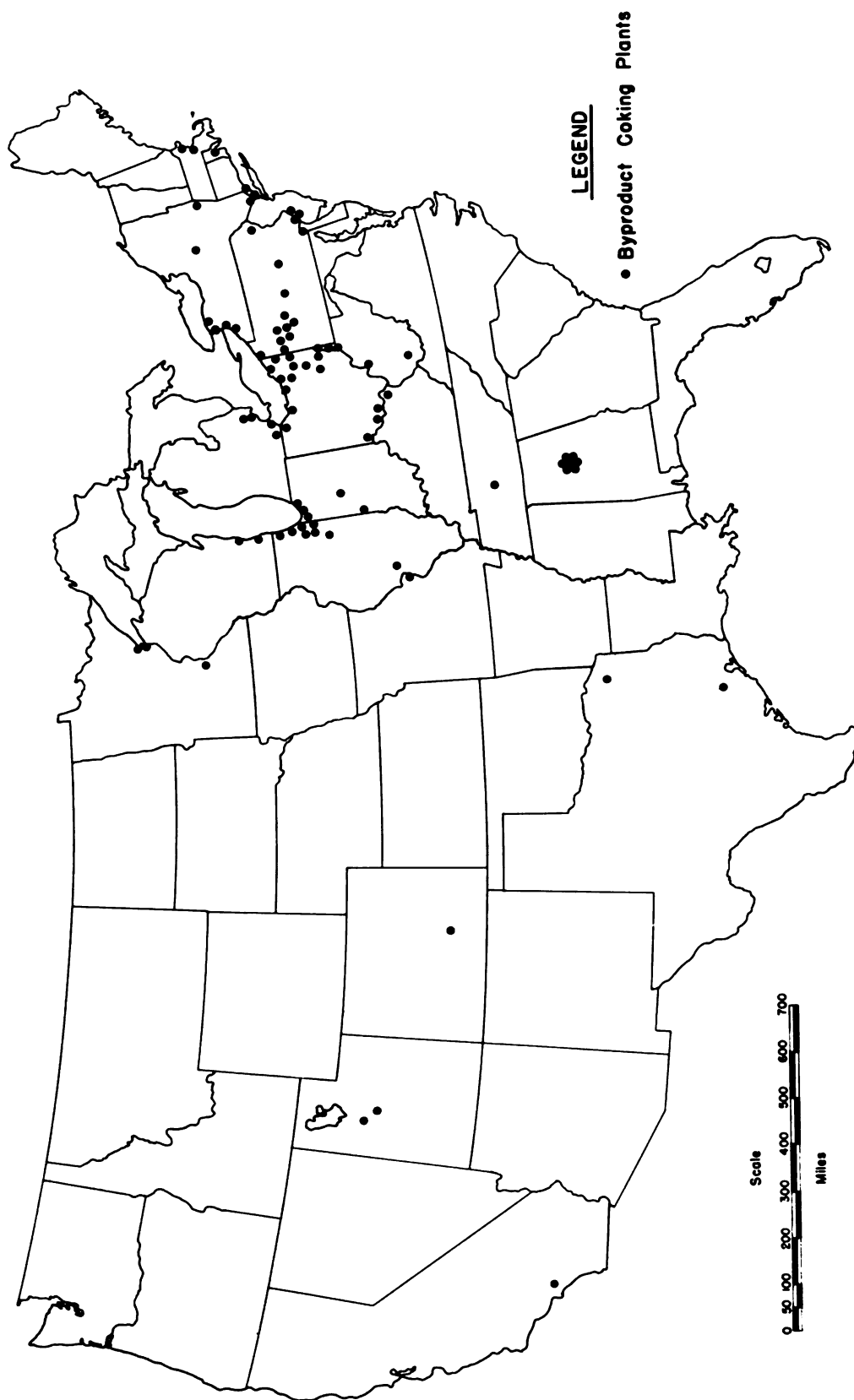
TABLE 15. - Synthetic ammonia plants in operation in the United States^{1/2/}

Company	Location	Capacity, tons/year	Capital costs	
Allied Chem. & Dye Corp.	Hopewell, Va.	255,000	-	Ammonia fertilizer solutions, nitric acid, ammonia, sodium nitrate, nitrosyl chloride.
Do.	South Point, Ohio	3/200,000	\$38,000,000	Ammonia, nitric acid, urea.
Commercial Solvents Corp.	Sterlington, La.	3/59,000	17,000,000	Ammonium nitrate, ammonia, methanol.
Dow Chemical Corp.	Pittsburg, Calif.	4,000	-	Ammonia.
Dow Chemical Co.	Freeport, Tex.	-	-	
E. I. Dupont de Nemours & Co.	Belle, W. Va.	200,000	-	Ammonia urea, methanol, urea-ammonia, ammonium carbonate.
Hercules Powder Co.	Niagara Falls, N.Y.	9,000	-	Ammonia.
	Pinole, Calif.	12,000	-	Ammonia, nitric acid, mixed nitric and sulfuric acid and ammonium nitrate.
Hooker Electro Chem. Co.	Tacoma, Wash.	14,600	1,894,700	Ammonia.
Lion Oil Co.	El Dorado, Ark.	3/208,000	29,000,000	Ammonium nitrate solutions, ammonia, nitric acid, ammonium sulfate.
Mathieson Alkali Corp.	Lake Charles, La.	3/63,000	14,000,000	Ammonia, nitric acid, ammonium nitrate.
Do.	Morgantown, W. Va.	3/200,000	53,000,000	Ammonia converted to natural gas at a cost of \$8,600,000.
Mathieson Chem. Corp.	Niagara Falls, N.Y.	7,000	-	Ammonia.
Midland Ammonia Works	Midland, Mich.	15,000	-	Do.
Mississippi Chem. Corp.	Yazoo City, Miss.	44,000	6,037,500	Ammonia, nitric acid, ammonium nitrate.
Penn. Salt Mfg. Co.	Wyandotte, Mich.	12,000	-	Ammonia.
Phillips Chem. Co.	Etter, Tex.	3/130,000	26,000,000	Do.
Smith-Douglas Co.	Houston, Tex.	3/22,000	2,000,000	Do.
Shell Chemical Corp.	Shell Point, Calif.	3/75,000	-	Ammonia, ammonium sulfate.
Spencer Chemical Co.	Military, Kan.	3/160,000	30,000,000	Ammonia and nitric acid.
Do.	W. Henderson, Ky.	3/69,000	15,000,000	Do.
Tenn. Valley Authority	Muscle Shoals, Ala.	3/66,000	11,000,000	Ammonia and ammonium nitrate.

^{1/} Cope, W. C., Ammonia: Part I U. S. Production Facilities: Chem. Ind., vol. 64, No. 6, June 1949, pp. 920-925.

^{2/} National Production Authority Release No. 2382.

^{3/} Plants built by Federal Government during World War II and sold or leased to present operators.



APR 9, 13

Figure 6. - Location of byproduct ammonia plants.

Nitric acid plants are located in 20 States; the total number of plants is 32. The geographic distribution of the States manufacturing nitric acid in 1952, was as follows: Alabama 3; Arizona 1; Arkansas 1; California 2; Colorado 1; Illinois 1; Indiana 1; Kansas 1; Louisiana 2; Massachusetts 1; Mississippi 1; Missouri 1; New Jersey 4; New York 2; Ohio 1; Pennsylvania 3; Texas 2; Virginia 1; Washington 2; and Wisconsin 1.

Control of Synthetic Ammonia Plants^{8/}

Aside from the Muscle Shoals development by the Government during World War I, the synthetic ammonia industry developed as a privately owned industry until the outbreak of hostilities in 1941. Compared with the large number of producers of by-product nitrogenous materials, the number of producers of synthetic ammonia has always been small. The list includes E. I. Dupont de Nemours & Co., Allied Chemical & Dye Corp., Dow Chemical Co., and its affiliated Midland Ammonia Co., Mathieson Alkali Works, Inc., Pennsylvania Salt Manufacturing Co., and Hercules Powder Co., all of which had entered the field before 1940.

Production of synthetic ammonia on a commercial basis began in the United States in 1921, and production of synthetic sodium nitrate began in 1929. By 1934 there were 8 active plants with a reported capacity of 341,350 tons of synthetic ammonia annually. In 1940, 7 companies operated synthetic ammonia plants with a total capacity of 390,300 tons. To assure adequate supplies of nitrogen to meet military demands, which rose from 39,000 tons in 1939 to about 600,000 tons per year at the close of World War II, the Government built 10 new plants. In 1945, the total annual ammonia plant capacity of the United States, including that of the 10 Government plants, was 1,496,100 tons, of which the Government owned 800,000 tons of synthetic and 5,000 tons of byproduct capacity, and private companies owned 431,000 tons of synthetic and 260,000 tons of byproduct capacity. The synthetic capacity far exceeded other fixed nitrogen capacity, and roughly two-thirds of the synthetic capacity was Government owned.

With this large Government capacity in existence, the distribution of total capacity did not change appreciably until nine of the Government plants were sold outright or leased to private interests. The resulting ownerships of synthetic ammonia plants and capacities existing in 1952 are given in table 16.

Process Materials Consumed

The process materials consumed in the manufacture of nitric acid, ammonium sulfate, and ammonia annually, and per ton of finished product, is given in table 1. The process requirements for the manufacture of these compounds were calculated, in part, from published data on the operation of the Lion Oil Co. chemical plant at El Dorado, Ark.

Personnel

Plant-operating personnel must include highly qualified supervisors, semitechnical laborers, engineers, machinists, and mechanics for the effective and safe operation and maintenance of high-pressure equipment. It is estimated that 80 percent of the manpower required for a nitrogen plant could be trained in the plant and would require no specialized skill before employment.

^{8/} Federal Trade Commission, The Fertilizer Industry: Report, 1950, pp. 23-24.

TABLE 16. - Ownership of synthetic ammonia capacity in 1952

Company	Rated annual capacity	Percent of total capacity
Allied Chem. & Dye Corp.....	455,000	25.0
E. I. Dupont de Nemours & Co.....	209,000	11.5
Shell Chemical Co.....	75,000	4.1
Hercules Powder Co.....	12,000	.7
Dow Chemical Co.....	33,600	1.8
Mathieson Chem. Co.....	270,000	14.8
Penn. Salt Mfg. Co.....	12,000	.6
Lion Oil Co.....	208,000	11.4
Commercial Solvents Co.....	59,000	3.2
Spencer Chemical Co.....	229,000	12.6
Phillips Chemical Co.....	130,000	7.1
Smith-Douglas Co.....	22,000	1.2
Tenn. Valley Authority.....	66,000	3.6
Mississippi Chem. Corp.....	43,200	2.4
Total synthetic capacity.....	1,823,800	100.0

The personnel requirements for the operation of a nitrogen plant will depend on the variety of finished products and on the efficiency of the plant. The efficiency of a nitrogen plant depends upon the hydrogen source, the size of the plant, and the system of conversion. A plant using natural gas as its hydrogen source tends to have lower costs than a plant using coke, but what fuel will be used will depend on the relative cost of each. The average number of employees per ton of finished product ranges from 1.0 to 1.7. Approximately 111 employees are needed for an efficient plant, 120-ton-per-day ammonia capacity. For a smaller plant, 100-ton-per-day capacity, about 100 employees will be required. Estimated personnel requirements of a 120-ton-per-day ammonia plant, producing ammonia and ammonium nitrate, using either the Claude or the American system of conversion are given in table 17.

TABLE 17. - Operating personnel (120-ton-per-day ammonia plant)^{1/}

Type of employees	Claude process	American system
Administrative, clerical.....	46	61
Ammonia plant.....	24	80
Maintenance and service includes nitric acid and ammonium nitrate plant.....	41	65
Total.....	111	206

^{1/} Shearon, W. L., Jr., and Thompson, H. L., Ammonia at 1,000 Atmospheres: Ind. Eng. Chem., vol. 44, February 1952, p. 263.

The estimated annual payroll for a 120-ton-per-day ammonia plant, using the Claude process, and producing ammonium nitrate, is tabulated in table 18.

TABLE 18. - Estimated annual payroll (120-ton-per-day ammonia plant using Claude process)^{1/2/}

Type of employees	Number of employees	Average hourly rates	Annual amount
Manager.....	1	\$	\$ 15,000
Supervision.....	15	2.88	90,000
Administrative, clerical.....	19	1.59	63,000
Chemical engineers.....	12	2.88	72,000
Laborers.....	45	1.75	163,800
Maintenance, service.....	19	1.90	75,000
Total.....	111		\$478,800

1/ The estimated payroll includes a premium payment for shift differential, compensation insurance, and Social Security.

2/ Includes integrated nitric acid and ammonium nitrate plant.

Geographical Areas of Consumption

Fertilizer

Consumption of nitrogen fertilizer compounds, by States and regions, is given in table 19. Although the United States used more fertilizer in 1950-51 than in 1949-50, a number of States used less. North Dakota used 5 percent less nitrogen in 1950-51 than in 1949-50. Montana increased its consumption of nitrogen fertilizers, 656 percent in 1950-51, compared with 1949-50. The demand in the West North Central States has increased greatly percentage-wise in recent years, but the quantity consumed remains relatively small. The West North Central States used 7.3 percent of the total nitrogen consumed in the United States agriculture in 1950-51. Largest users of nitrogen are the States east of the Mississippi River; these States used 65 percent of the 1,171,418 short tons of nitrogen consumed in the continental United States in 1950-51.

Industry

The relative importance of the geographical areas of consumption may be shown by the cities in which large quantities of synthetic ammonia are stored. Large stock points are located in the following cities: Syracuse, Boston, New York, Newark, St. Louis, Philadelphia, and Chicago. At these points, consumers can secure prompt delivery. These stock points supply the ammonia used in industry.

Need for Additional Plants

The need for additional chemical nitrogen plants is indicated by the expansion requested by the Government for completion in 1955. The total nitrogen requirement, in 1955, is estimated at 2,930,000 tons of nitrogen, an increase of 1,291,000 tons over the 1952 production capacity (table 10). Thirty-one companies have plans to enter the chemical nitrogen field, but some of them may not complete their plans. The Government is not providing money for this expansion, but is allowing tax benefits through accelerated amortization of capital investments.

Farmers in some areas have interested themselves in cooperative synthetic ammonia and nitrogen fertilizer plants. Possible advantages for such cooperative ownerships are: (1) The plants' products are designed to alleviate a regional fertilizer problem; (2) the profits of the plant are returned to farmers; and (3) the costs of fertilizer may be reduced owing to lower freight costs, and cooperatives' privilege of not paying Federal income tax if profits are distributed to the members.

Chemical nitrogen plants have been proposed at La Platte, Neb., and Lawrence, Kans. The plant at La Platte will produce urea, which is used as a cattle feed and may not appreciably alleviate the fertilizer problem in the West North Central States. The plant at Lawrence, Kans., if built, will reduce the present need for a nitrogen plant in North Dakota, but future needs will greatly exceed the proposed capacity of this plant.

The various reasons for increased fertilizer consumption in the North Central States have been summarized by Mehring^{9/} under the following headings: (1) Farm income; (2) education and demonstration; (3) changes in crops; (4) soil depletion; and (5) miscellaneous.

Changes in crops grown have increased the need for plant food in maintaining crop yields and have been an important factor with growing demand for fertilizer. Since 1940 the North Central States have increased the acreage of corn and soybeans and have decreased the acreage of alfalfa. At the same time, there has been a rapid change to higher yielding varieties, such as hybrid corn and Clinton oats. To take full advantage of yield possibilities of hybrid corn, many farmers who received little benefit from fertilizers when they grew corn from their own seed, must fertilize the crop. Furthermore, when seed is purchased at prices ranging from \$7.00 to \$12.00 per bushel instead of being saved from the previous crop, the farmer has more incentive to buy fertilizer to obtain the highest possible yield.

The farming system, the weather, and the natural soil-building processes result in less soil depletion in the North Central States than in those parts of the country where most of the fertilizer is used, but many years of cropping have reduced the plant-food reserves of even the rich prairie soils.

RESOURCES AVAILABLE IN NORTH DAKOTA

The resources required for a chemical nitrogen industry are available in North Dakota. Process requirements are: Coal or natural gas, power, and water.

Coal

Coal deposits underlie all or part of 29 counties in western North Dakota and 7 counties in northwestern South Dakota (about 41,000 square miles).^{10/}

Most of the lignite beds of North Dakota are in the Fort Union formation, which forms the bedrock deposit in the western one-third of North Dakota and a portion of the northwestern corner of South Dakota. With a few local exceptions, the lignite deposits of North Dakota are flat, with only minor regional dips toward the west and northwest.

^{9/} Mehring, A. L., Fertilizer Consumption and Supply in the North Central States: Better Crops With Plant Food, Reprint U-5-48, 16 pp.

^{10/} Ford, Bacon, and Davis, Inc., Engineers, The Synthetic Liquid Fuel Potential of North Dakota and South Dakota: New York, 1950-52, p. 85.

Over 100 lignite beds with thicknesses exceeding 4 feet have been reported in western North Dakota. The average thickness of overburden in operating strip mines is 33 feet.

Water

Adequate and dependable supply of water in North Dakota for a synthetic ammonia industry is available in the main stem of the Missouri River, and in some of its tributaries. The runoff from the drainage area of the Missouri River above Bismarck, N. Dak. (186,400 square miles), has averaged 1.4 inches, or about 14,000,000 acre feet per year.

The flow of the Souris River is erratic. From 1935 to 1942 the average flow, at the gaging point above Minot, was only 13,470 acre feet per year. Below Minot, there are approximately 7,000 acres of irrigated land. In addition to existing water demands, the Souris River is a poor water source because of heavy pollution during low-flow periods. The Souris River has had periods of no flow.

The use of water in the Missouri River Basin is subject to the provisions of the 1944 Flood Control Act (Public Law 534). The Secretary of Defense is authorized to make contracts for the sale of surplus water from a reservoir under his control. The State engineer of North Dakota has general supervision of the waters of the State. Application must be made to the State engineer for appropriation of water. The control of pollution of the public waters of North Dakota is vested in the State Water Conservation Commission and the State Game and Fish Department. Before any construction of systems to dispose of waste is begun, approval must be obtained from the State Water Conservation Commission and the State Department of Health.^{11/}

Natural Gas

Present production of commercial natural gas is obligated to the Montana-Dakota Utilities Co. However, the Williston Basin is a new source of natural gas and the Signal Oil & Gas Co. will construct a \$15,000,000 natural gasoline plant near Williston, N. Dak., which is expected to be in operation in the fall of 1954. It is reported that the ultimate plant capacity will be 60 million cubic feet of gas daily, which will yield about 250,000 gallons of natural gasoline. Butane, propane, and sulfur also will be produced.^{12/} The resultant dry gas will be sold by the Amerada Petroleum Corp.

In 1949 the average value of natural gas at producing wells in North Dakota was 5.2 cents per M cubic feet. In 1950, the average value of natural gas consumed by electric utilities in South Dakota and Minnesota was 21.8 cents per M cubic feet.^{13/} During 1950 no natural gas was consumed in electric generating plants in North Dakota. The present rate for commercial gas at Mandan, N. Dak., is 34 cents per M cubic feet, but this gas is subject to interruptable service, when gas is needed for firm users.^{14/} The rate at which a nitrogen plant could obtain gas probably might be in the range from 20 to 30 cents per M cubic feet.

^{11/} See reference cited in footnote 10, pp. 117-118.

^{12/} Williston Basin Oil Review, July 1953, p. 7.

^{13/} See footnote 4.

^{14/} Montana-Dakota Utilities Co. rate.

Electric Power

Hydroelectric Power

The Garrison power plant being constructed on the Missouri River, north of Bismarck, N. Dak., is scheduled for initial operation in 1955. It will have an installed capacity of 400,000 kilowatts and will generate an average of 1.7 billion kilowatt hours per year. The expected cost of electric power to a large consumer is about 5.5 mills per kilowatt hour. The power from this hydroelectric project has been allotted, but there is expected to be a surplus of 110,000 kilowatt hours in the Garrison power market in 1960.^{15/}

Local Utilities

The Montana-Dakota Utilities Co. is constructing two new power plants in North Dakota; one at Mandan and the other at Williston. The Mandan plant will be a 25,000 kilowatt steam electric generating unit; the Williston plant will be an 8,000-kilowatt gas turbine installation. The Mandan plant is scheduled for completion in September 1954, and the Williston plant is 95 percent complete.^{16/} The new plant of the Central Electric Power Cooperative, at Voltaire, N. Dak., has an installed capacity of 40,000 kilowatts. This plant is operating at about 50 percent capacity. About 10,000 kilowatts would be required by a 120-ton-per-day ammonia plant. Hence, it would appear that enough power is available, particularly at Voltaire and Mandan. The Mandan plant is expected to begin operation at 50 percent of capacity, and surplus power will be available.

Freight Rates^{17/}

Railroad freight is shipped under either a class or a commodity rate. Where there are no published commodity rates, manufactured fertilizers are shipped under a class E rate, the lowest of the class rates. The great bulk of freight is shipped under commodity rates, and most of the freight revenue results from these shipments. A commodity rate usually is lower than the class rate. It applies to large shipments moving long distances, to low-grade articles on short hauls, and to especially competitive traffic. The Interstate Commerce Commission, Class Rate Investigation, Docket No. 28300, exhibit No. 228 (1942) states:

Of the carload of freight originating on September 23, 1942, on all railroads in the United States, 85.2 percent moved under commodity rates. Commodity rates accounted for 77.6 percent of the revenue from carload traffic,

Rail freight rates on interstate shipments are initially established by the carrier concerned, subject to the ultimate prescription of the Interstate Commerce Commission in a proper proceeding in which all interested parties are given an opportunity to state their views. Some factors considered in establishing freight rates are: (1) Cost of the service to the carrier; (2) value of service to shipper; (3) value of the article; (4) nature of article; (5) risk in handling the article; (6) distance of the haul; (7) bulk and weight of the article; (8) whether special facilities or extra services are required; (9) volume of traffic and periods of

^{15/} Bureau of Reclamation, Power-Resources, Requirements, and Supply: 1951, p. 59.

^{16/} Minneapolis Star, Mar. 9, 1953, p. 1.

^{17/} Richards, L. E., Studies of the Effect of Freight Rates on Marketing: Min. Eng., vol. 187, February 1950, p. 387.

movement; (10) competition between producing centers; (11) whether or not movement will be based on rate; and (12) prospects of car being returned loaded or empty. Rates are said to be governed by the three C's: Competition, comparison, and compromise.

Comparison of Rates

Rail rates for manufactured fertilizers show a wide variance. Tables 20 and 21 give freight rates for phosphate rock and superphosphate from producing plants to Bismarck, N. Dak.

TABLE 20. - Rail freight rates for superphosphate from producing plants to Bismarck, N. Dak.

Plant location	Miles	Rate per ton
Anaconda, Mont.....	709	12.54
Don, Idaho.....	941	17.30
Montpelier, Idaho.....	1,034	17.30
Sheffield, Ala.....	1,286	15.20
Mobile, Ala.....	1,584	17.19
Mount Pleasant, Tenn.....	1,288	15.78

TABLE 21. - Rail freight rates for ground phosphate rock from producing plants to Bismarck, N. Dak.

Plant location	Miles	Rate per ton
Anaconda, Mont.....	709	12.54
Don, Idaho.....	941	17.30
Montpelier, Idaho.....	1,034	17.30
Sheffield, Ala.....	1,286	15.20
Mobile, Ala.....	1,584	17.19
Mount Pleasant, Tenn.....	1,288	15.78

Table 22 gives the freight rates for carload shipments of sodium nitrate from both operating and proposed ammonia plants to North Dakota points, and table 23 gives the freight rates for tank car shipments of anhydrous ammonia to the same points.

A study of the freight rate tables shows that freight moving south to north has a much lower rate than freight moving west to east. These increased freight costs work to the disadvantage of plants located in North Central States. A graph showing the spread in freight rates for ammonia nitrate fertilizer is given in figure 7.

Market Area

The market area in which a new chemical nitrogen plant can compete with existing plants depends on the new plants' transportation advantage, if costs of production are equal. Freight rates for manufactured nitrogen fertilizers from Bismarck, N. Dak., to distributing centers in adjacent states, is given in table 24, together with rates from competing plants to the same points.

TABLE 22. - Freight rates for railroad tank car shipments of anhydrous ammonia (rate per cwt.)^{1/}

Ammonia plant location	Velva, N. Dak.	Bismarck, N. Dak.	Grand Forks, N. Dak.	Fargo, N. Dak.
Etter, Tex.....	1.66	1.65	1.48	1.42
Tacoma, Wash.....	2.40	2.40	2.40	2.40
Billings, Mont.....	1.77	1.77	2.18	2.18
Pasco, Wash.....	2/2.40	2/2.40	2/2.40	2/2.40
Vicksburg, Miss.....	3/1.63	3/1.58	3/1.47	3/1.41
Yazoo City, Miss.....	3/1.72	3/1.67	3/1.54	3/1.48
W. Henderson, Ky.....	3/1.41	3/1.40	3/1.24	3/1.18
South Point, Ohio.....	1.48	1.47	1.32	1.24
Morgantown, W. Va.....	3/1.56	3/1.54	3/1.36	3/1.31
St. Louis, Mo.....	3/1.24	3/1.19	3/1.08	3/1.01
Buras, La.....	3/1.84	3/1.80	3/1.68	3/1.63
New Orleans, La.....	3/1.79	3/1.70	3/1.62	3/1.56
Freeport, Tex.....	3/1.94	3/1.92	3/1.76	3/1.71
La Platte, Nebr.....	3/1.01	3/.92	3/.89	3/.81
Sterlington, La.....	3/1.68	3/1.66	3/1.53	3/1.48
Houston, Tex.....	3/1.87	3/1.86	3/1.70	3/1.63
Military, Kans.....	3/1.95	3/1.87	3/1.80	3/1.70
Lake Charles, La.....	3/1.14	3/1.13	3/1.04	3/1.01
Belle, W. Va.....	3/1.52	3/1.50	3/1.35	3/1.26
Niagara Falls, N. Y.....	3/1.48	3/1.47	3/1.32	3/1.24
Midland, Mich.....	3/1.31	3/1.31	3/1.13	3/1.07
Wyandotte, Mich.....	3/1.34	3/1.32	3/1.18	3/1.09
Hopewell, Va.....	3/1.75	3/1.72	3/1.57	3/1.50
Sheffield, Ala.....	3/1.64	3/1.58	3/1.48	3/1.40
Pryor, Okla.....	3/1.43	3/1.40	3/1.24	3/1.19
Ventura, Calif.....	3/1.22	3/1.22	3/1.22	3/1.22
Shell Point, Calif.....	3/1.22	3/1.22	3/1.22	3/1.22
Pittsburg, Calif.....	3/1.22	3/1.22	3/1.22	3/1.22
Pinole, Calif.....	3/1.22	3/1.22	3/1.22	3/1.22

1/ Present rates 15 percent above rates quoted plus 3 percent Government tax.

2/ Minimum 30,000 pounds in tank cars.

3/ Minimum 50,000 pounds in tank cars.

The points where the rates from existing plants and the rates from Bismarck, N. Dak., are equal determine the approximate outline of the market area for a plant site at Bismarck. The market area for this site is shown in figure 8. It includes North Dakota, South Dakota, Minnesota, and parts of Iowa, Nebraska, and Wisconsin; also shown is the effect of a proposed plant at La Platte, Nebr., in reducing the market area of the Bismarck, N. Dak., plant.

Freight rates for newly established industries are controlled by class rates, until the growth of traffic leads to the publication of commodity rates. The market area of the Bismarck plant site will grow when commodity rates replace the higher class rates.

TABLE 23. - Freight rates for rail shipments of sodium nitrate
(carload lots) (rate per cwt.)^{1/}

Ammonia plant location	Velva, N. Dak.	Bismarck, N. Dak.	Grand Forks, N. Dak.	Fargo, N. Dak.
Etter, Tex.....	3/.98	3/.96	3/.85	3/.83
Tacoma, Wash.....	1.77	1.77	1.77	1.77
Billings, Mont.....	.82	.82	.97	.97
Pasco, Wash.....	2/1.77	2/1.77	2/1.77	2/1.77
Vicksburg, Miss.....	3/.81	3/.80	3/.75	3/.72
Yazoo City, Miss.....	3/.82	3/.81	3/.75	3/.73
W. Henderson, Ky.....	2/.69	2/.68	2/.62	2/.60
South Point, Ohio.....	.72	.71	.65	.64
Morgantown, W. Va.....	3/.84	3/.82	3/.78	3/.75
St. Louis, Mo.....	3/.66	3/.64	3/.59	3/.56
Buras, La.....	3/.90	3/.89	3/.83	3/.81
New Orleans, La.....	3/.87	3/.84	3/.81	3/.78
Freeport, Tex.....	3/.94	3/.93	3/.86	3/.84
La Platte, Nebr.....	3/.56	3/.52	3/.51	3/.46
Sterlington, La.....	3/.83	3/.82	3/.77	3/.75
Lake Charles, La.....	3/.91	3/.90	3/.83	3/.82
Houston, Tex.....	3/.91	3/.90	3/.83	3/.81
Military, Kans.....	3/1.03	3/.99	3/.97	3/.92
Belle, W. Va.....	3/.73	3/.73	3/.66	3/.63
Niagara Falls, N. Y.....	3/.72	3/.71	3/.65	3/.62
Midland, Mich.....	3/.65	3/.65	3/.59	3/.56
Wyandotte, Mich.....	3/.66	3/.65	3/.60	3/.57
Hopewell, Va.....	2/.82	2/.81	2/.75	2/.72
Sheffield, Ala.....	3/.84	3/.81	3/.78	3/.75
Pryor, Okla.....	3/.73	3/.72	3/.66	3/.64
Ventura, Calif.....	4/1.22	4/1.22	4/1.22	4/1.22
Shell Point, Calif.....	4/1.22	4/1.22	4/1.22	4/1.22
Pinole, Calif.....	4/1.22	4/1.22	4/1.22	4/1.22
Pittsburg, Calif.....	4/1.22	4/1.22	4/1.22	4/1.22

1/ Present rates 15 percent above rates quoted plus 3 percent Government tax.

2/ Minimum 30,000 pounds. 3/ Minimum 40,000 pounds. 4/ Minimum 50,000 pounds.

TABLE 24. - Freight rates for manufactured nitrogen fertilizers
to distributing centers in North Central States
(per ton dry in bags)^{1/}

Destination	Plant location		Destination	Plant location	
	Bismarck, N. Dak.	Military, Kans.		Bismarck, N. Dak.	Military, Kans.
Chicago, Ill.	12.40	10.60	Scotts Bluff, Nebr.	13.20	12.40
St. Louis, Mo.	12.60	8.40	Aberdeen, S. Dak.	6.60	12.20
Des Moines, Iowa	11.80	8.40	Sioux Falls, S.Dak.	9.20	10.20
Minneapolis, Minn.	10.20	11.00	Billings, Mont..	12.40	
Concordia, Kans..	12.60	7.20	Cedar Rapids, Iowa	12.00	9.60
Mankato, Minn.	10.20	10.40	Bismarck, N. Dak.		14.00
Omaha, Nebr.	11.20	7.60			

1/ Rates include ex parte 175-B increase.

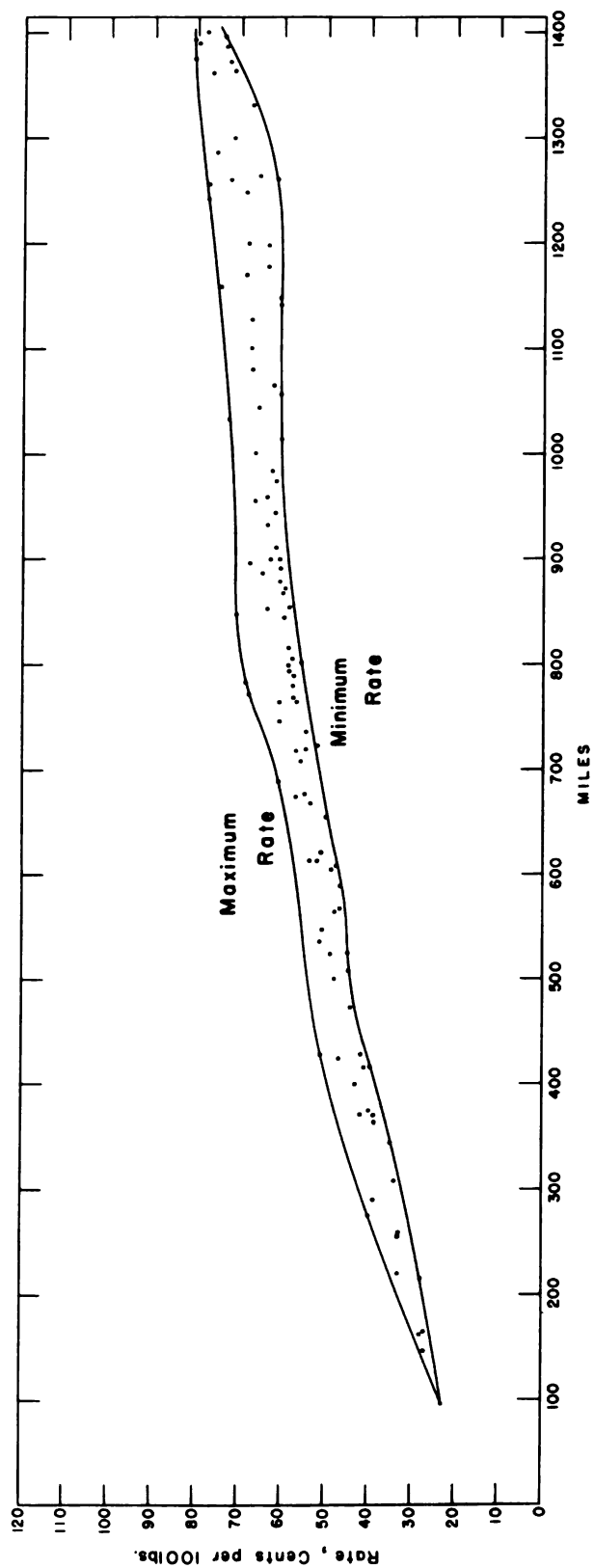


Figure 7. - Spread in freight rates for ammonium nitrate fertilizers.

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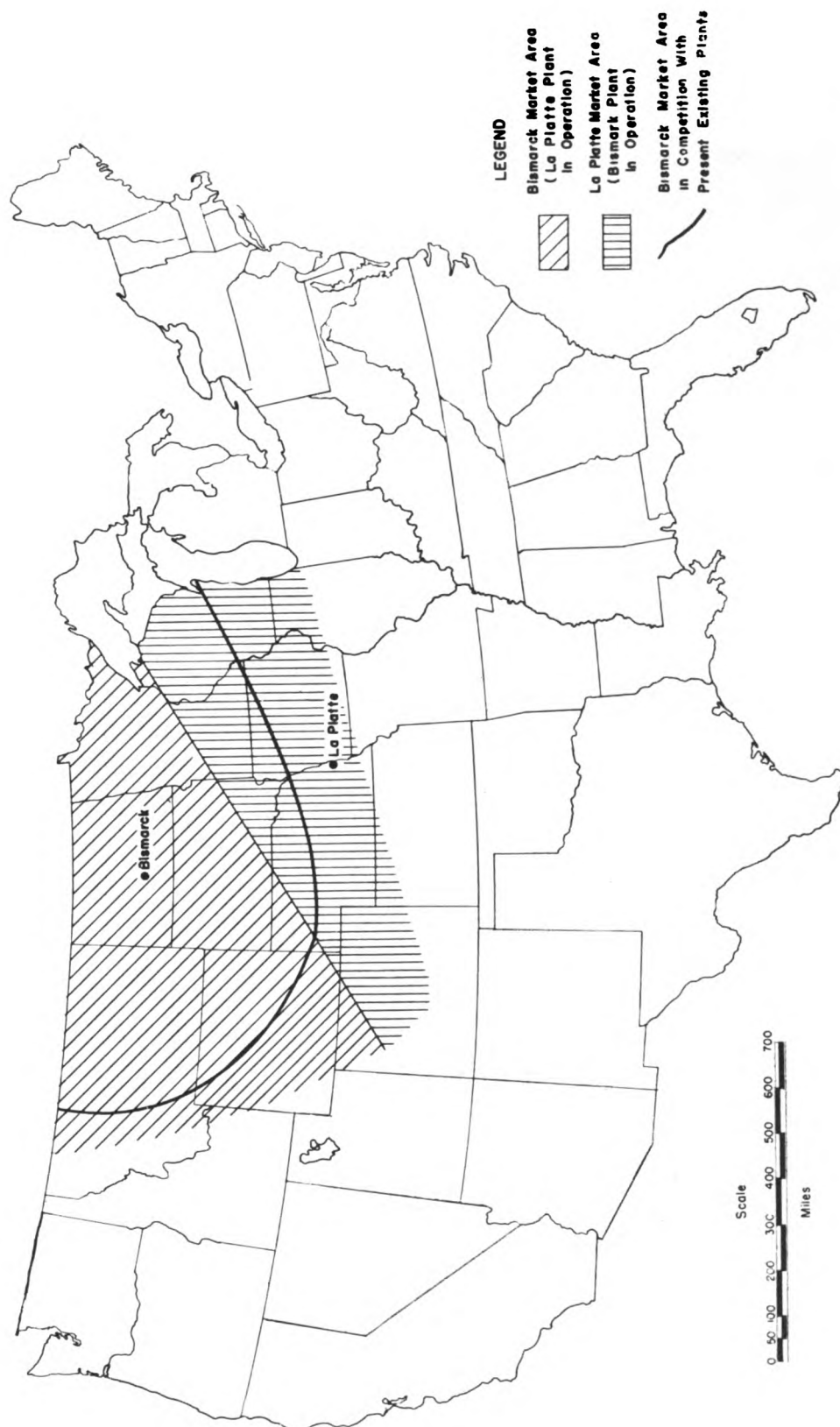


Figure 8. - Proposed market area.

PROCESSES

Direct Synthetic Ammonia Processes Using Catalysts

In the direct synthetic process ammonia is synthesized from a gas consisting of 3 parts of hydrogen and 1 part nitrogen. The purified gas is brought into contact with a catalyst, such as specially prepared porous iron granules. At elevated temperatures, and under high pressure, this hydrogen and nitrogen unite to form ammonia. Even without the catalyst the hydrogen and nitrogen would combine in minute amounts; the catalyst can only hasten the reaction. Several systems depend on this principle: The Haber in Germany, the Claude in France, the Casale in Italy, and the American in the United States. The Haber was the first system to employ the direct synthetic method, and the other later processes were variations of the original process.^{18/}

Haber - Bosch Process

The Haber - Bosch process was the product of research conducted in Germany; it was placed on a successful basis in 1913. Water gas and producer gas are sources of hydrogen and nitrogen, which are induced to form ammonia at 200 atmospheres and 550° C. in the presence of iron oxide as a catalyst. Unreacted gases are recirculated after ammonia is recovered. Ammonia recovery of 8 percent per pass through the converter is achieved.

Mont Ceniz Process

The Mont Ceniz process is named for the company that built the first installation. The process is similar to the Haber. It functions at a comparatively low pressure of 100 atmospheres and a temperature of from 420° to 500° C. Use is made of a highly active iron cyanide catalyst. The gases are precleaned and fuel is saved by a system of heat exchangers. Since this is a low-pressure system, capital and operating costs are less than with the Haber process.

Claude Process

The Claude process was developed in France by Georges Claude. It operates at higher pressures and temperatures; namely, 900 atmospheres and 600° C. Ammonia recovery of 40 percent is reported. The system works satisfactorily with relatively large amounts of inert gases.

Casale Process

This Italian process operates at 475° C. and about 750 atmospheres. Ammonia recovery of 40 percent is claimed. A special catalyst of unusually long life is employed. This process was designed to use hydrogen produced by electrolysis of water.

American Process

The American process was developed by the United States Department of Agriculture. The process operates at 300 atmospheres and 475° C. Efficient catalysts consisting of iron, potassium, and aluminum oxides are employed. A photograph of the Tennessee Valley Authority plant using the American system of ammonia synthesis is shown in figure 9.

^{18/} Riegel, E. R., Industrial Chemistry: Reinhold Publishing Co., 1937, p. 113.

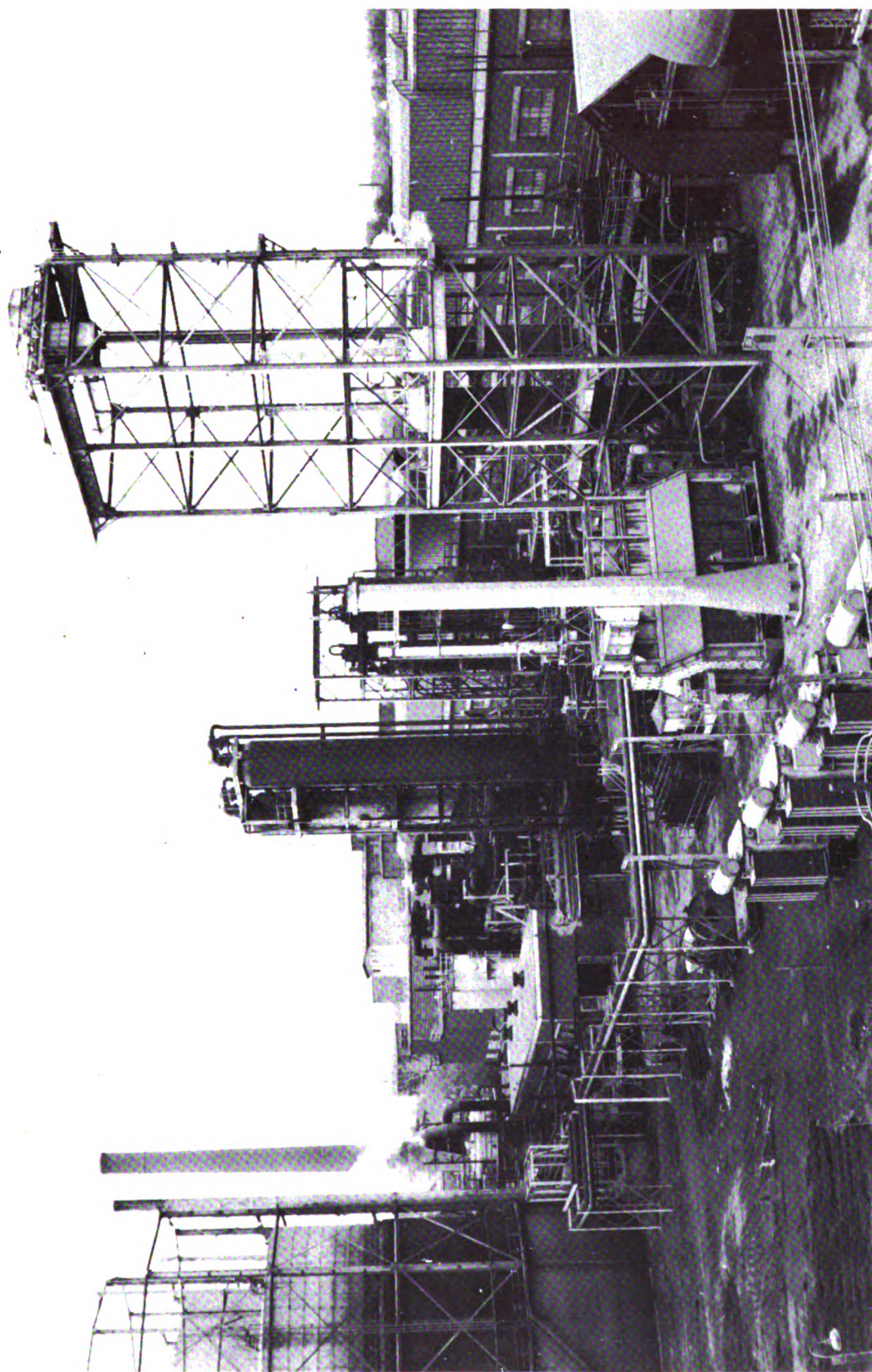


Figure 9. - TVA's ammonia plant at Wilson Dam, Ala. (Photograph courtesy of Tennessee Valley Authority.)

New Processes

Nitric acid. - Food Machinery & Chemical Corp. has developed a process for direct thermal fixation of atmospheric nitrogen and is installing a plant expected to produce 40 tons of 100 percent nitric acid per day at Lawrence, Kans., for the Army Ordnance Department. In the process the reactors produce 2 percent nitric oxide, which is absorbed and catalytically oxidized on silica gel. By changes in condition and time cycle, nitrogen dioxide or nitrogen trioxide can be produced. The nitrogen trioxide may be converted to nitric acid and the military interest lies in the possible use of nitric oxide or nitrogen dioxide as a rocket fuel.

Development of refractories capable of withstanding thermal shock at the process temperature above 2,200° C. was the principal technical problem. If this new process is developed and all technical problems solved, it might make the present-day nitric acid processes obsolete.^{19/}

Superphosphate. - New processes are being investigated using nitric acid and mixture of nitric and sulfuric acid to manufacture superphosphates.^{20/}

For many years the nitrogen industry has discussed methods of acidulating phosphate rock with acids other than sulfuric. Simple acidulation with nitric acid does not produce a satisfactory superphosphate since it contains calcium nitrate, which is corrosive, unstable, and extremely hygroscopic. Calcium nitrate formation is prevented by controlling the $\text{CaO}/\text{P}_2\text{O}_5$ mole ratio at 2.0 or less. In Process I (see fig. 10), which is similar to that used by I. G. Farbenindustrie, the P_2O_5 is extracted from the phosphate rock by mixed nitric and phosphoric acids, followed by ammoniation, drying, and addition of KCl . The first steps produce a mixture of dicalcium phosphate, ammonium nitrate, and ammonium phosphate. Process II (see fig. 10), which is similar to the French P. E. C. process, uses a mixture of nitric and sulfuric acids for extracting the P_2O_5 from the phosphate rock. The mixture then is ammoniated, producing a slurry of dicalcium phosphate, ammonium nitrate, and calcium sulfate. After the addition of KCl , the product is dried. Process III (see fig. 10) is similar to Process II, except that it uses no sulfuric acid, obtaining the necessary sulfate by addition of K_2SO_4 or $(\text{NH}_4)_2\text{SO}_4$ instead of KCl . The final Process, IV, is a special one, producing dicalcium phosphate and ammonium nitrate. The P_2O_5 is extracted from the phosphate rock with nitric acid, then ammoniated to precipitate dicalcium phosphate, which is filtered and dried. The filtrate is treated with CO_2 and ammonia to precipitate the CaCO_3 , and the resulting ammonium nitrate solution is evaporated and crystallized.

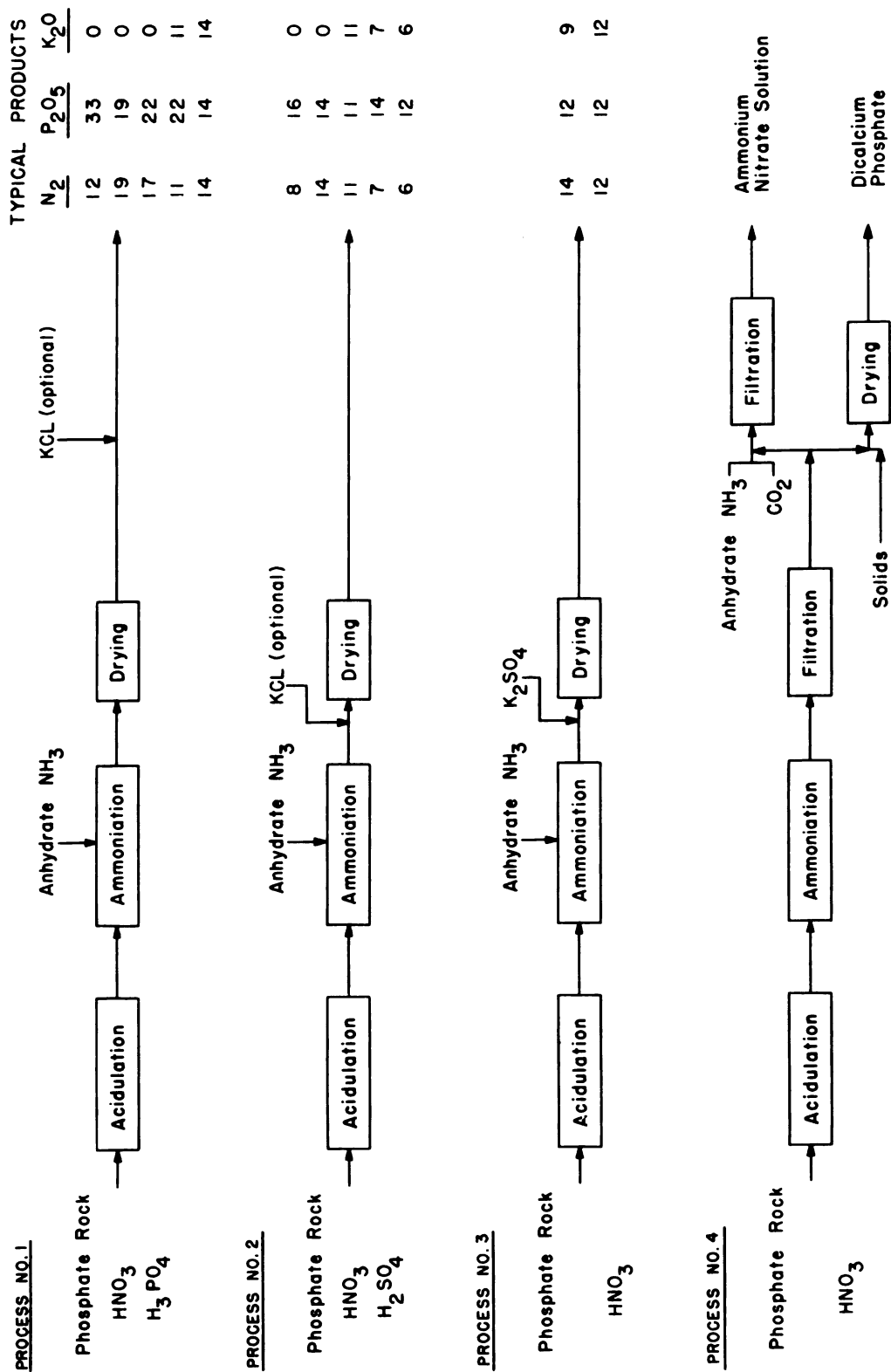
PROCESSES APPLICABLE TO THE RESOURCES OF NORTH DAKOTA

Ammonia Manufacture

The Claude process for the manufacture of synthetic ammonia is the process that may be most applicable to the resources of North Dakota. The main reason for this assumption is that this process will function with a larger amount of methane in the synthesis gas than any other process. About 2 percent methane is formed during gasification of lignite and in processes other than the Claude the methane tends to poison the catalysts. The processes described below are based on the Claude system of synthetic ammonia production, but all standard ammonia processes will work with natural gas as the hydrogen source.

^{19/} Inskeep, G. C., and Henry, T. H., Nitric Acid in Great Britain: Ind. Eng. Chem., vol. 45, July 1953, p. 1387.

^{20/} Chemical Engineering, N-P-K Head for Dizzy Peaks: Vol. 60, March 1953, p. 202.



SOURCE: N-P-K HEAD FOR DIZZY PEAKS, Chemical Engineer, March 1953 - p.202

April 23, 1953

Figure 10. - Flow scheme of superphosphate production.

Lignite as Hydrogen Source

Since 1945, the Bureau of Mines has been working on the development of a gasification process using lump lignite as a raw material for the production of hydrogen gas. This process could be integrated with any direct synthesis process for the production of ammonia. A flow-scheme of the production of synthetic ammonia using this process is given in figure 11. A description of the gasification process follows:^{21/}

Lignite is gasified in an annular reaction space 3 inches wide and 20 feet high, which is formed by two concentric metallic cylinders having approximate diameters of 48 and 42 inches, respectively. The large cylinder is heated from the outside by three rows of gas burners located at different levels of the cylinder. Incoming combustion air to the burners is preheated by heat exchange with burner products of combustion, which are at 1,600° F. Lump lignite is fed to charging dome on top of the gasifier retort by a gas-tight feeding device, and descends slowly through the annular reaction space, along with super-heated steam, which meets it at the top. The lignite first dries and then heats up to the temperature where thermal decomposition of the coal substance and reaction of the steam with the carbon occur. As the temperature progressively increases toward the lower section of the annulus, the rate of gasification increases and more and more gas is formed. Temperatures are as high as 1,925° F. in the lower part of the combustion chamber.

Gas leaves the annular reaction zone through the gas offtake at its lower end and travels upward through the inner retort tube, transferring part of its sensible heat through the wall to the descending lignite. The gas subsequently passes through a scrubbing system where it is cooled and cleared of dust. Char refuse is discharged from the bottom of the retort.

Depending on operating conditions, gas yield per ton of natural lignite can be rather widely varied. Average yield, since gasifier has been in operation, is about 44,750 cubic feet per ton of lignite.

A 95 to 96 percent pure hydrogen can be obtained by catalytically converting with steam the carbon monoxide in the gas to hydrogen and carbon dioxide and scrubbing out the latter.

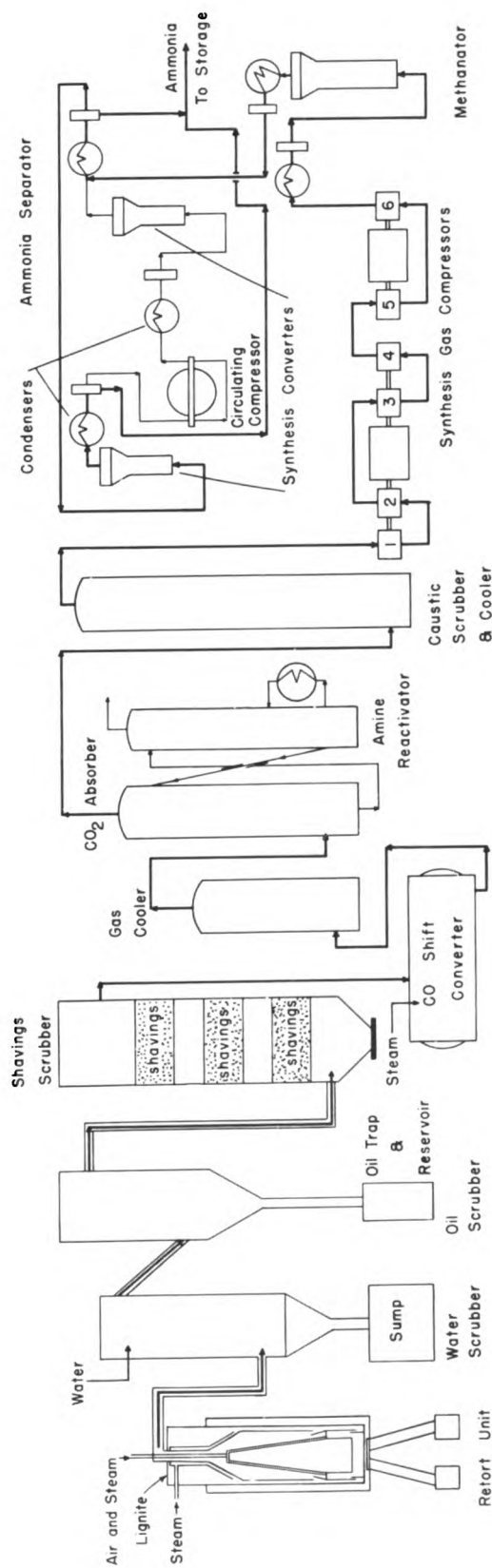
Natural Gas Reforming

The following is a description^{22/} of the production of synthetic ammonia at the Mississippi Chemical Co. plant at Yazoo City, Miss., by the Claude process. This plant is the first farmer-owned plant in the United States, and it was designed to give efficient production with the least capital outlay. Figure 12 gives an idea of the magnitude of a plant producing 120 tons of ammonia per day. A flow-scheme of the production of synthetic ammonia using this process is given in figure 13.

In the production of hydrogen from natural gas, superheated steam, and natural gas, in the ratio 2:1, are introduced into the tubes of the reformer furnace, together with flue gas from the boilers and/or tail gas from the nitric acid plant as a source of nitrogen. Natural gas is approximately 92 percent methane, with 3

^{21/} Chemical Processing, Bureau of Mines Pilot Plant Proves Lignite Gasification Feasible: Vol. 15, May 1952, p. 54.

^{22/} Thompson, H. L., and Shearon, W. H., Jr., Ammonia at 1,000 Atmospheres: Ind. Eng. Chem., vol. 44, February 1952, p. 265.



Gasification:
U.S. Bureau of Mines Pilot Plant, Grand Forks, N.D.

Synthesis:
After Mississippi Chemical Corporation Plant, Yazoo City, Mississippi

Figure 11. - Flow scheme of synthetic ammonia production, lignite as hydrogen source.

April 27, 1953

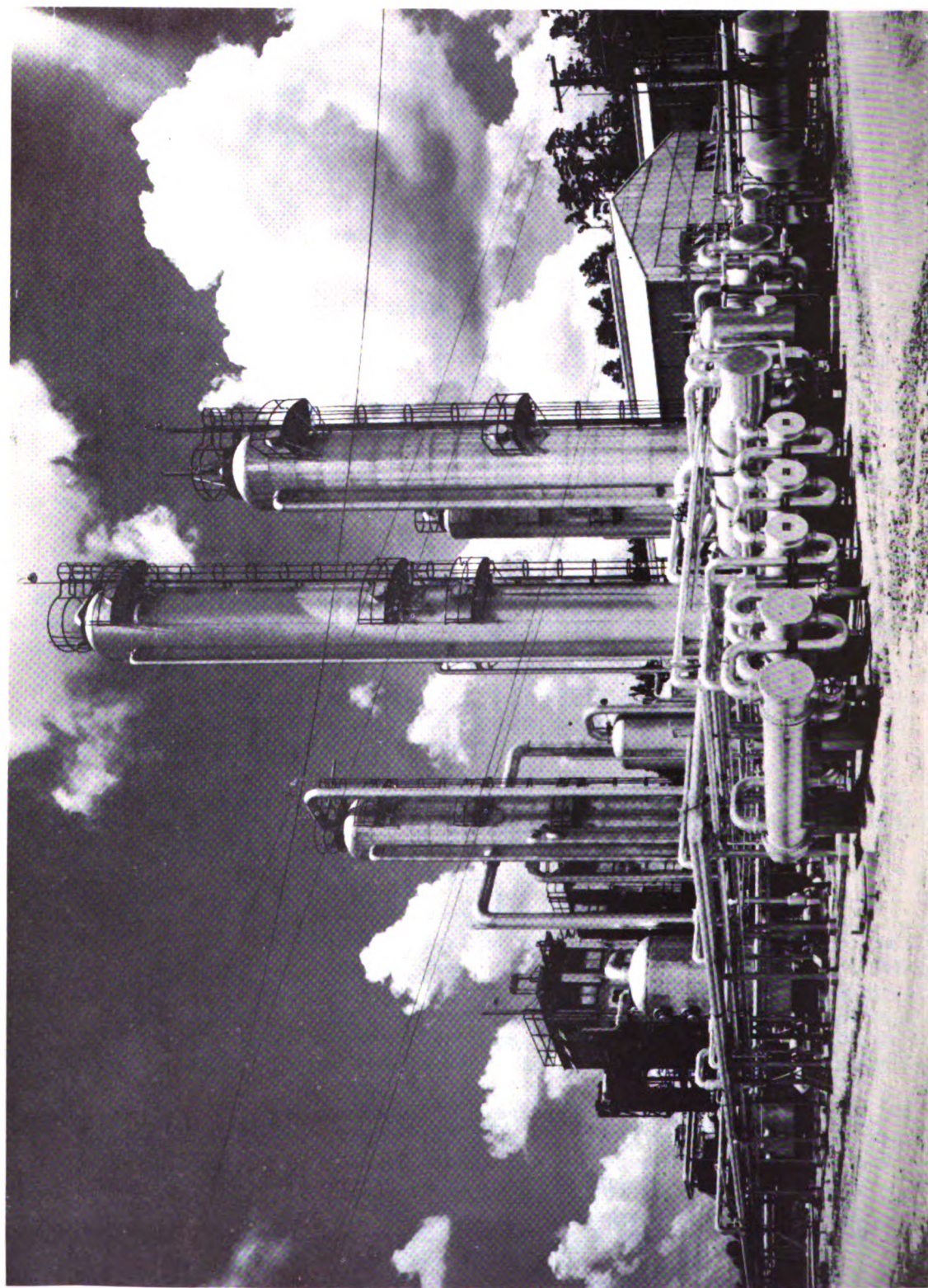
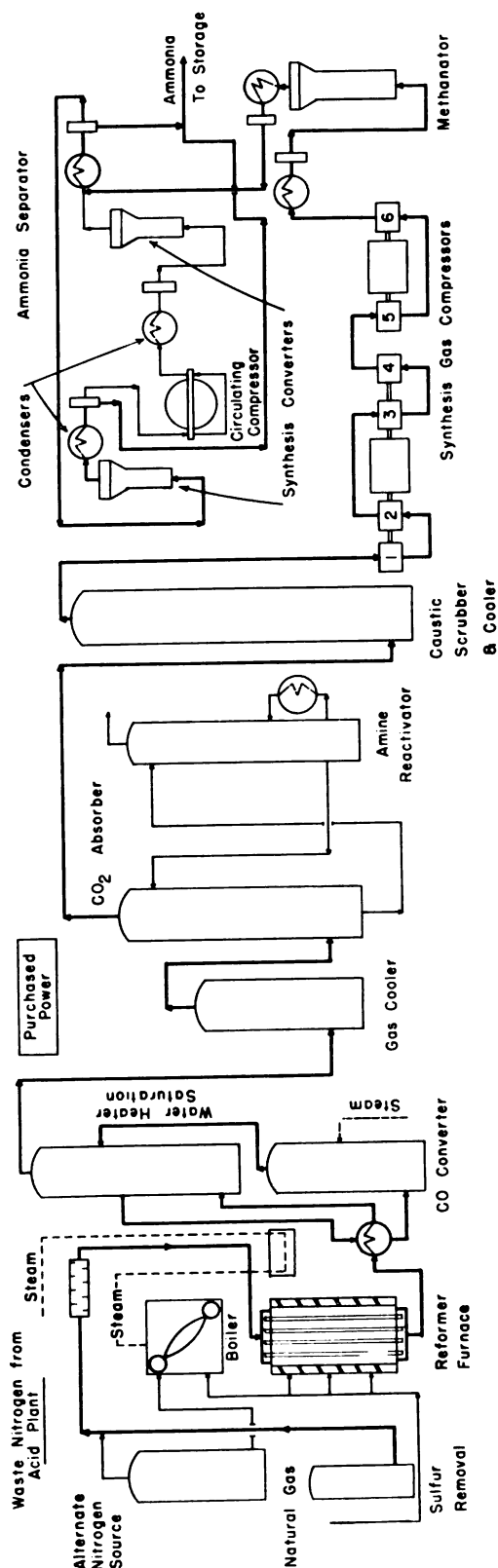


Figure 12. - Monoethanolamine gas purification plant, Mississippi Chemical Corp., Yazoo City, Miss.
(Photograph courtesy of Mississippi Chemical Corp.)



April 27, 1953

Figure 13. - Flow scheme of synthetic ammonia production, Claude system.

After Mississippi Chemical Corporation Plant, Yazoo City, Mississippi
Taken from Ammonia at 1000 Atmospheres, W. H. Shearon Jr. & H. L. Thompson
Ind. and Engr. Chem., Feb. 1952 p. 258

percent mixed hydrocarbons plus a small amount of sulfur. The sulfur is removed by activated carbon before the gas enters the reformer. Boiler flue gas is approximately 86 percent nitrogen, and the nitric acid tail gas is about 95 percent nitrogen.

Approximately 30 percent of the total natural gas is used as fuel in the reformer furnace, and 25 percent is used to fire the boilers.

One 12-foot diameter carbon steel vessel 65 feet high serves both reformers. It consists of two separated sections as a unit, the upper section packed with 15 feet and the lower section with 25 feet of 3-inch Raschig rings. The lower tower serves as the saturator; the upper tower as the water heater. Gas effluent from the converters enters the bottom of the upper tower, flows countercurrently to quenching water, heats the water to nearly boiling, and passes out the top of the tower of the gas cooler. The hot water passes down into the lower section where it meets the reformer effluent gas coming from the tube side of the heat exchangers. This gas is thus saturated with steam for the water gas shift reaction, which takes place in the converters, passes out the top of the bottom section, through the shell side of the exchangers, and to the two converters. Here the carbon monoxide reacts with steam, in the presence of an iron-chromium catalyst, to form carbon dioxide and additional hydrogen. The converter gas is cooled, and the carbon dioxide is absorbed by amine solutions. The gas then enters the caustic scrubber for final removal of the carbon dioxide. The last trace of carbon monoxide is removed in the synthesis stage by methanation; this is simply the reverse of the first reforming reaction, catalytically converting the carbon monoxide to methane.

Synthesis Stage

The gas from the caustic scrubber is compressed in 6 stages to 15,000 pounds per square inch. Because the synthesis reaction is reversible, the rate of conversion to ammonia approaches zero as ammonia content approaches equilibrium, making equilibrium by a single exposure of the gas to reaction conditions not feasible. Because of the incomplete approach and incomplete conversion at equilibrium, ammonia must be removed from the freshly reacted gas and the unreacted gas returned to the reaction zone. Two converters are used in series, and the unreacted gases are recirculated. The two converters are carbon steel cylinders, 25.75 inches inside diameter and 16.67 feet high, with shells 10.375 inches thick. A removable basket, or cartridge, fits inside the shell and contains the heat exchange tubes holding approximately 16.5 cubic feet of catalyst per converter, and electric heating coils for startup and temperature control. The catalyst is a carefully purified magnetic iron oxide, doubly promoted with small percentages of aluminum and potassium oxides. Synthesis gas enters at the bottom of the converters, is preheated by passing around the converter tubes and is passed through the catalyst in the tubes. Ammonia-bearing gas is discharged from the top of the converters. Temperature of the catalyst is controlled by a bypass stream of cold gas introduced into the bottom of the converter shell through a separate opening. The gas, precooled on exit from the converter tops, is cooled further for ammonia condensation, then passed through an ammonia separator from which liquid ammonia goes to a receiver and storage. The unreacted gases are recirculated.

Since a small amount of methane was introduced in the methanation step and it is not possible to eliminate completely other inert gases from the system, these inerts tend to accumulate. This causes a reduction in ammonia at equilibrium and purging of inerts is required. The purged gas is high in methane and is used as fuel for the boilers.

Chemical Nitrogen Products Manufacture

Synthetic ammonia produced in an ammonia plant, in general, is converted to other chemical nitrogen products before it is consumed in agriculture. The ammonia may be converted to urea or ammonium nitrate. An intermediate step in the manufacture of ammonium nitrate is the manufacture of nitric acid. The processes used in the manufacture of these end products are given below.

Production of Urea

Urea is produced from carbon dioxide and ammonia (see fig. 14). It has a chemical formula $\text{CO}(\text{NH}_2)_2$ and is a white crystalline solid containing 46 percent nitrogen.

The ammonia and carbon dioxide are compressed and heated separately to keep from forming solids in the compressors. The reactions take place in the converter at 2,000 to 2,500 pounds per square inch and at 160° to 180° C. About 40 percent of the gases are converted to urea per pass. Reduction of pressure and application of heat drives off the unconverted gases, which may either be recycled or sent to some other plant. The urea-water solution that is left is evaporated and dried.

Production of Nitric Acid^{23/}

A considerable portion of the ammonia produced by the direct synthetic process is changed to nitric acid by catalytic oxidation.

Ammonia is oxidated by air with the subsequent absorption of the nitrous gases in water at ordinary pressure, or under a pressure of 100 pounds. In either case the principle of the method is that a mixture of air and ammonia gas (11 percent NH_3) passed through a fine wire gauze of activated platinum raised to a glowing heat, combine to form nitric oxide (NO) and water. The first reaction ($4\text{NH}_3 + 5\text{O}_2 = 4\text{NO} + 6\text{H}_2\text{O}$) takes place at a rapid rate, with a 95 percent, or more, conversion. The time of contact is 0.0014 second.

The oxidized gases leaving the converter pass through heat exchangers, cooling pipes of chrome steel, and reach the absorption towers, which are fed countercurrently with water and weak acid. Here nitric oxide is converted to nitrogen dioxide ($2\text{NO} + \text{O}_2 = 2\text{NO}_2$). This is a slow reaction; but it is accelerated by cooling gases. In the absorption towers, the reaction $3\text{NO}_2 + \text{H}_2\text{O} = 2\text{HNO}_3 + \text{NO}$ takes place. The NO formed is reoxidized to NO_2 in the towers and is gradually all absorbed. The nitric acid from the absorption tower contains 50 percent HNO_3 .

For many purposes 50 percent nitric acid is satisfactory, but for nitration processes it must be concentrated to 95 or 98 percent by adding 66° B. sulfuric acid and distilling.

Production of Ammonium Nitrate

Ammonium nitrate is produced by neutralizing nitric acid with ammonia. The resulting solution is filtered, concentrated, and crystallized. The crystallized product is dried, crushed, and screened to desired size. To improve the quality of the product, a clay conditioner is added in the final state to prevent caking.

^{23/} Riegel, E. R., Industrial Chemistry: Reinhold Publishing Co., 1937, pp. 126-127.

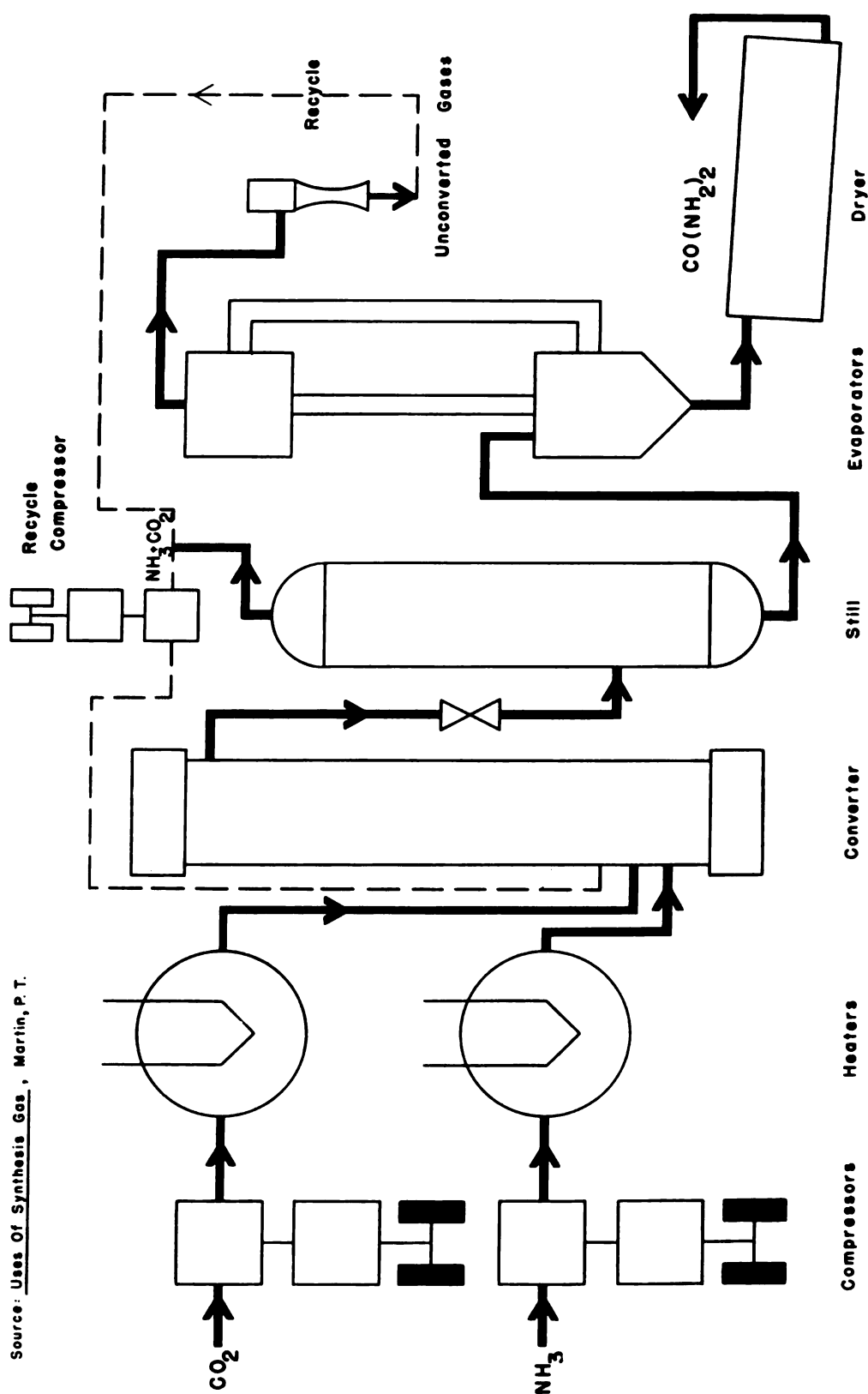


Figure 14. - Flow scheme of urea production.

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OTHER POTENTIAL INDUSTRIES USING NITROGEN COMPOUNDS

A chemical nitrogen plant supplies raw materials for various other industries such as: (1) Explosives; (2) plastics; (3) chemicals; and (4) metallurgy. These are potential industries for North Dakota.

Explosives

Ammonia and nitric acid form the base for explosives, which in peace time consume about 10 percent of the ammonia produced in the United States. Nitric acid is the nitrating agent for the manufacture of nitroglycerin from glycerin, TNT from toluene, picric acid from phenol, nitrocellulose from cellulose. RDX explosive is made by reacting ammonia with formaldehyde and nitrating the product.

Consumption of explosives in iron mining in Minnesota accounted for approximately 33,000,000 pounds of explosives in 1952. Larger quantities of explosives will be required as the proportion of low-grade taconites mined increases.

Plastics

Ammonia may be combined with carbon dioxide to form urea. Urea is utilized in the manufacture of urea-formaldehyde resins and urea-furfural resins, which are important plastics. Urea is used in plastic wood and dimethylol-urea in transmuted wood. Ammonia is used as a catalytic agent in producing several plastics, such as the phenol-formaldehyde type. Celluloid, pyroline, viscoloid, and fibreloid are made from nitrocellulose.

Use of plastics in the United States is increasing rapidly. Sales of plastic pipe alone for 1953 may exceed \$15,000,000; compared with \$500,000 in 1948. Plastics are fast replacing metals in numerous items because of the ease of forming, together with great strength. The relative lightness of plastics and high value of each individual item enable plastic items to be shipped long distances. Plastics are a potential industry in North Dakota.

Chemicals

The production of petroleum and natural gas from the Williston Basin may provide the raw materials to establish a chemical industry in North Dakota. Ammonia is used to produce nitric acid. Nitric acid is used in organic synthesis to produce nitrobenzol, nitroparaffins, and many other nitro-compounds, such as amines. Ammonia is used in manufacturing caustic soda by the Solvay process.

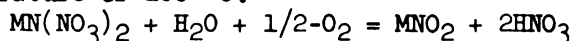
Metallurgy

Certain metals, such as manganese, copper, and nickel, may be extracted from their ores with ammonia and nitric acid. Application of such a method might result in utilization of the manganese deposits in Minnesota and South Dakota. A description of the Nosson process for extracting manganese is as follows:^{24/}

The process starts with the grinding of ore to -60 mesh. A reduction of the ore in a reducing atmosphere follows; the greater part of the manganese goes to manganese oxide, and the iron oxide is reduced to ferrous-ferric oxide. In the following leaching operation with nitric acid, the

^{24/} Nosson, E. S., Manganese Concentration From Low-Grade Domestic Ores, Nosson Nitric Acid Cycle: Ind. Eng. Chem., vol. 43, July 1951, p. 1696.

ferrosoferric oxide remains insoluble with silicon dioxide and aluminum oxide. Sulphuric acid added to the nitric acid takes care of the barium, calcium, and lead which remain as sulfates in the gangue. If, however, the ore contains an excess of calcium, it would be more economical to work only with nitric acid and produce calcium nitrate for fertilizer as a byproduct. Phosphorous remains in the insoluble remainder. The solution of manganese nitrate is concentrated and decomposed in the presence of air at a temperature of 200° C.



Manganese dioxide and nitric acid leave the decomposition unit. The manganese dioxide is purified by washing, and then is dried. It is nodulized if it is to be used for metallurgical purposes. The washed and dried manganese product contains 60 percent manganese; its manganese dioxide content is 88 percent xxx.

COST ANALYSES OF PLANT AND MANUFACTURING

Factors Governing the Choice of Plant Sites

The factors governing the choice of a plant site are as follows: (1) Availability of transportation; (2) availability of process materials; (3) labor market; (4) housing facilities; and (5) other industry.

Availability of Transportation

Construction and operation of a synthetic ammonia plant usually requires a direct rail and highway connection. Railroad facilities are fairly well distributed in North Dakota (see fig. 15), since the transcontinental lines of the Great Northern, Northern Pacific, and Chicago, Milwaukee, St. Paul & Pacific Railroads cross the State, and since the State's position as one of the Granger States results in the development of numerous branch feeders to these lines. The Minneapolis, St. Paul, & Sault Ste. Marie Railroad also serves part of North Dakota.

The highway pattern of the State is influenced by the few important cities and recreational areas, such as the Black Hills and Yellowstone and Glacier Parks; with the result that paved roads are not widely distributed. Except for some sections of the western half of the State, there is a well-developed network of secondary roads.

Availability of Process Materials

Process materials available in North Dakota for a synthetic nitrogen plant are coal, natural gas, and water.

Large quantities of lignite are available for production of the hydrogen necessary for the manufacture of synthetic ammonia. Natural gas will also be available as soon as processing plants are built in the Williston Basin area and will probably provide a cheaper source of hydrogen.

The coal deposits of North Dakota contain 16 percent of the coal reserves in the United States and underlie all or part of 29 counties in western North Dakota. Figure 6 indicates the general areas of coal availability.

The present commercial production of natural gas is limited and comes from an extension of the Cedar Creek field of Montana. The wells are near the Montana-Dakota boundary in southwestern Bowman County, N. Dak. The gas enters the

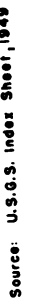


Figure 15. - Railroad facilities of North Dakota.

Montana-Dakota Utilities Co. pipeline system, which supplies natural gas to Williston and Bismarck, N. Dak.

The Williston Basin is expected to produce large quantities of natural gas. An indication of the minimum amount of natural gas that may be expected is the report that the Signal Oil and Gas Co. plant now under construction near Tioga, N. Dak., will have an ultimate capacity of 60,000,000 cubic feet per day.

Electric power in sufficient quantities to operate an ammonia plant is available from the Voltaire plant of the Central Electric Power Cooperative, and the Mandan plant of Montana-Dakota Utilities Co. The Voltaire plant has a capacity of 40,000 kilowatts and at present is operating at about 50 percent plant capacity. New power plants are being built at Mandan and Williston, N. Dak., of 25,000 and 8,000 kilowatt capacity, respectively.

The water supply in the streams throughout the region of the coal resources varies greatly. Figure 6 indicates the water resources of North Dakota with relation to the general areas of coal availability.

The only large source of firm water in or near the coal areas are the main stems of the Missouri River. The run-off from the drainage area of the Missouri River above Bismarck, North Dakota (186,400 square miles), has averaged 1.4 inches, or approximately 14,350,000 acre feet per year.^{25/}

Labor Market

North Dakota is mainly agricultural, hence all of the labor needed to operate a chemical plant would probably not be available in the plant locality. Enough key labor for training purposes could be recruited from other chemical plants. A method of employing key personnel to train local workers has been used at the Yazoo City, Miss., plant of the Mississippi Chemical Corp. Excellent results were reported. Workers were hired 90 days before the plant began to operate and were trained in a school established in the plant. Some key workers were sent to nearby nitrogen plants for on-the-job training.

Housing Facilities

Housing facilities would not be available in North Dakota unless the ammonia plant were located near one of the larger cities. The extra cost of providing housing for a community complete with schools, stores, and facilities would increase the capital costs of the plant.

Other Industry

The economy of North Dakota is primarily agricultural. Recently, oil has been discovered in the Williston Basin. A refinery is planned at Mandan, N. Dak., by the Standard Oil Company of Indiana. Product pipelines will connect the Williston Basin to the present pipeline terminal in the Fargo-Moorhead area.

Factors Governing Selected Plant Capacity

The primary factor governing selected plant capacity is the demand for nitrogen fertilizer in the market area.

^{25/} See work cited in footnote 10, p. 102.

Consumption of nitrogen for fertilizer in 1951, in the proposed market area is given in table 25; together with an estimate of the new plants' share of market demand, based on freight advantage to the Bismarck plant site.

TABLE 25. - Nitrogen fertilizer consumption in market area

State	Nitrogen consumed ^{1/} 1951, tons	New plants' estimated share of demand, tons
Minnesota.....	7,312	6,000
Iowa.....	20,302	5,000
North Dakota.....	573	573
South Dakota.....	621	621
Nebraska.....	11,824	5,000
Montana.....	2,018	2,000
Wyoming.....	190	150
Totals.....	42,840	19,344

^{1/} Scholl, W., and Wallace, H. J., Consumption of Commercial Fertilizers in U. S., 1950-1951: Agr. Chem., vol. 7, June 1952, p. 40.

Capital Cost

Although a 120-ton-per-day plant is considered as the minimum economical size for an ammonia plant, estimated capital costs of 3 plant sizes - 60, 120, and 180 tons per day - are given in table 26. It is noted that the unit cost advantage accruing to the 180-ton plant as opposed to the 120-ton plant is relatively small. A breakdown of estimated investment costs of a 120-ton plant using natural gas and of a 120-ton plant using lignite gasification are given in table 27.

TABLE 26. - Relation of estimated costs to capacity of anhydrous ammonia plants^{1/2/}

Size, tons per day	Investment cost ^{3/4/}	Operating cost per ton ammonia ^{3/}
60.....	\$3,799,000	\$39.48
120.....	6,037,500	32.66
180.....	8,732,000	30.46

^{1/} Shearon, W. H., Jr., and Thompson, H. L., Ammonia at 1,000 Atmospheres: Ind. Eng. Chem., vol. 44, February 1952, p. 263.

^{2/} Natural gas reforming.

^{3/} Original figures related to early 1949 conditions; figure given is original figure multiplied by 1952 index factor.

^{4/} Includes integrated nitric acid and ammonium nitrate plant.

TABLE 27. - Estimated capital costs of 120-ton-per-day ammonia plant^{1/}

Item	Natural gas	Lignite gasification
1. Process equipment.....	\$3,498,300	\$4,978,000
2. Process and buildings.....	620,500	770,500
3. Process equipment erection.....	1,218,000	1,938,000
4. Steam facilities included in 1 and 2.....		
5. Site and site preparation.....	140,500	140,500
6. Water system.....	291,700	291,700
7. Power system.....	268,500	268,500
Total.....	\$6,037,500	\$8,387,200

^{1/} Includes integrated nitric acid and ammonium nitrate plants.

CONCLUSIONS

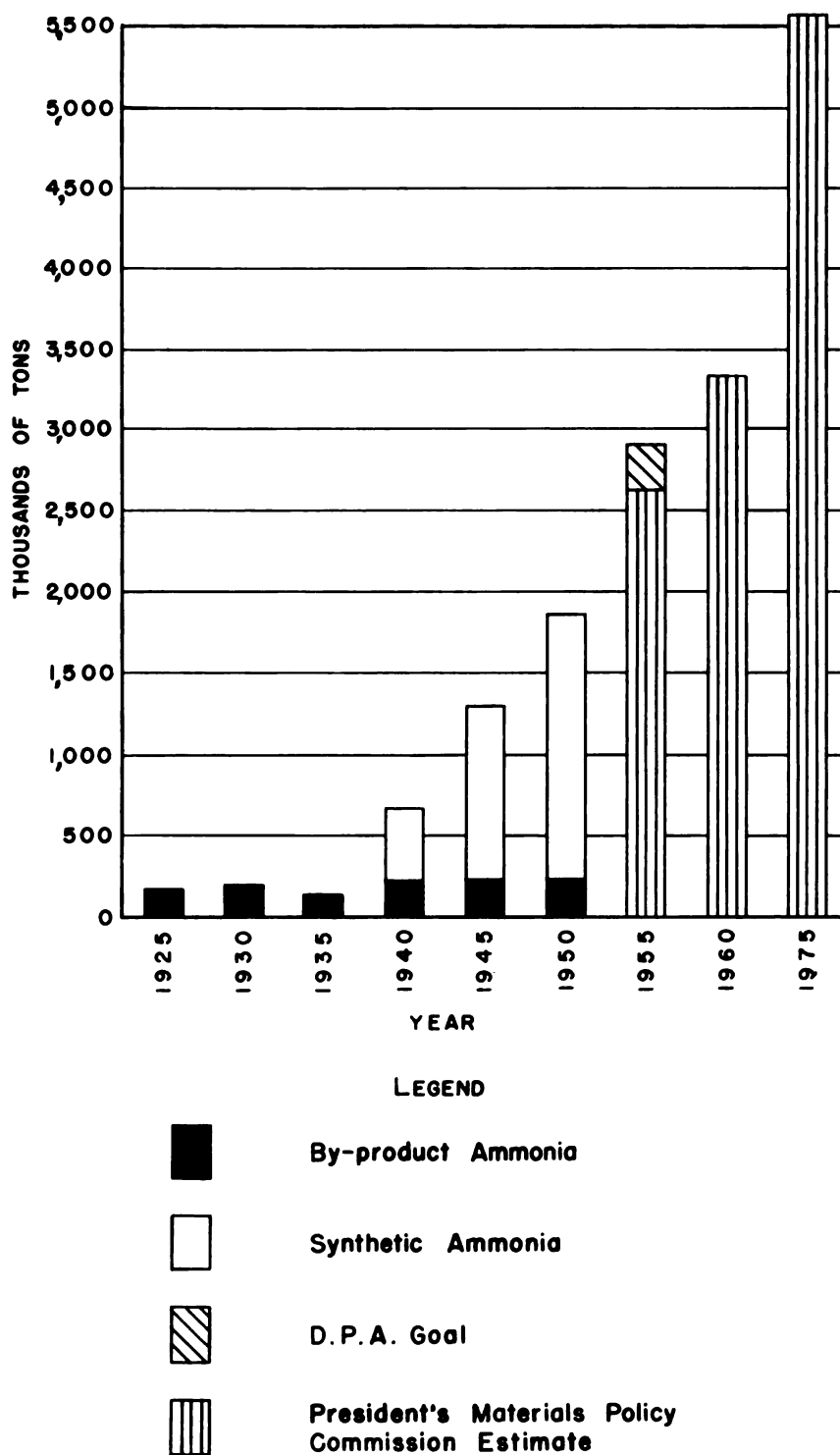
The manufacturing cost, excluding overhead and fixed charges, for a 120-ton-per-day plant is estimated at \$48.75 per ton of ammonia produced using natural gas and \$61.45 per ton of ammonia produced using lignite gasification. The production cost for a 60-ton plant using natural gas is estimated at \$59.65. The ammonia produced, in general, must be converted to other end products before it is used as nitrogen fertilizer.

The plant considered at Bismarck, N. Dak., would have facilities for converting part of its ammonia production to ammonium nitrate and manufacturing cost is estimated at \$40.82 per ton. This compares with a delivered price for ammonium nitrate originating at Military, Kans., of \$84.00 at Bismarck, N. Dak., \$80.20 at Sioux Falls, S. Dak., \$82.40 at Aberdeen, S. Dak., \$80.40 at Mankato, Minn., and \$81.00 at Minneapolis, Minn., including freight. The differences between estimated manufactured cost at Bismarck and the estimated delivery cost at above places indicate a substantial margin for plant amortization, interest, and profit.

The demands for ammonia appear to be pyramiding (see fig. 16); the real question is whether or not there will be enough even when the industry meets the projected DPA goal of 2,930,000 tons of nitrogen in 1955. One of the basic reasons for the tremendous demand for ammonia is the need for nitrogen in fertilizers. Fertilizer consumption has been growing constantly and future requirements probably will increase tremendously.

A large market area for nitrogen compounds exists in the North Central States. In North Dakota, the new petroleum industry may use nitrogen compounds in manufacturing petroleum products. The farmers of the North Central States are just beginning to use large amounts of nitrogen for fertilizers, and the use in the future will be much greater than at present. The Department of Agriculture estimates the West North Central States will use 319,000 tons of nitrogen by 1955.

It is indicated that under the present economic conditions a 120-ton-per-day ammonia plant in North Dakota may be economically feasible and that there is enough demand for its products. In the future, additional facilities may be added to take care of increased demands. Conservative cost estimates of raw materials, production, and capital expenses were used in making this analyses. When large quantities of natural gas and hydroelectric power are available, raw-material costs might be reduced by possibly one-third. This will lower the manufacturing cost of ammonia to about \$39.00 per ton. The present estimated manufacturing cost, using natural gas reforming, is \$48.75 per ton of ammonia.



NOTE: AFTER CHEMICAL AND ENGINEERING NEWS MAR. 1953

Figure 16. - Estimated future nitrogen requirements.

Raw materials for a chemical nitrogen plant in North Dakota are available in the large reserves of lignite and of natural gas. Natural gas will soon be available from a new natural gasoline plant near Tioga, N. Dak.

The increased profits that a farmer will receive if he uses more fertilizer, may be shown by the following statement by Bear.^{26/}

One pound of extra nitrogen, rightly used, can be depended upon to produce approximately 100 pounds of potatoes, 20 pounds of corn, 4 pounds of pork, 25 pounds of sugar, or 20 pounds of milk.

The nation cannot survive if it continues to mine its soil. Replacement of plant nutrients is a "must" if our living standard is to be kept high. An ammonia plant located in North Dakota will do much to alleviate the local fertilizer problem.

^{26/} Bear, F. E., Making the most of our Nitrogen Resources: Soil Sci. Soc., vol. 7, 1942, p. 298.

APPENDIX I

Selected Industrial Compounds From Ammonia

Compiled by A. C. Burr

Name	Uses
Ammonia NH_3	Reagent, insecticide, alkali, mold preventive, extractant, lubricant, hydrogenating agent, flotation reagent, neutralizing agent for acids, photographic reactant, cosmetic ingredient, soaps, dye, stain and spot remover, fire proofing, inks, fertilizer.
Ammoniacal magnesium cyanide	Fumigant for plants.
Ammoniated soap of palm and olive oils.	Wetting agent.
Ammonium acetate $\text{NH}_4\text{O}_2\text{CCH}_3$	Dyeing, medicinal, reagent, insecticide, mordant.
Ammonium acid adipinate	Leather buffer.
Ammonium acid diglycollate	Do.
Ammonium acid phthalate	Do.
Ammonium acid saccharate	Do.
Ammonium alginate	Ceramics (waterproofing), reagent, stabilizer, glues and adhesives, thickening ink, emulsifying agent, binder, defecating agent, mordant, waterproofing, clarifying agent.
Ammonium aluminum sulfate or - ammonium alum $(\text{NH}_4)_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$ - or - $\text{NH}_4\text{Al}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$	Fertilizer, flux, galvanizing of iron, reagent, clarifying agent, ingredient of catalytic, ingredient of portland cement, dyer, baking powder, confectionary, oleo-margin, inks, artificial stone, tanning, fireproofing, dyeing.
Ammonium aurintricarboxylate	Reagent, dye.
Ammonium benzoate $\text{NH}_4\text{O}_2\text{CC}_6\text{H}_5$	Preservative.
Ammonium Betatetrahydronapthalene - sulfonate	Emulsifying agent.
Ammonium bicarbonate or - ammonium acid carbonate, ammonium hydrogen carbonate NH_4HCO_3	Medicine, fire-extinguishing compounds, dye, leavening agent.

APPENDIX I (Con.)

Name	Uses
Ammonium bifluoride or - ammonium acid fluoride NH_4HF_2	Etch glass, sterilizing agent, textile sour, decomposing agent, mordant.
Ammonium borate or - ammonium biborate, ammonium acid tetraborate $\text{NH}_4\text{HB}_4\text{O}_7 \cdot 3\text{H}_2\text{O}$	Medicine, fire-retarding agents, condenser electrolytes.
Ammonium borofluoride	Casting processer for aviation engines.
Ammonium bromide NH_4Br	Bromide content in medicine, precipitating agent for silver salts in photography, reagent, soldering flux, fireproofing, sedative, printing.
Ammonium butylnaphthalene-sulfonate	Fire prevention.
Ammonium butyraldehydehydrate	Vulcanizing.
Ammonium butyrate	Emulsifying agent for leather, oils, soap; textile finishing.
Ammonium carbamate $\text{NH}_4\text{NH}_2\text{CO}_2$	Chemical-starting point, fertilizer.
Ammonium carbonate or - ammonium crystals $(\text{NH}_4)_2\text{CO}_3$	Theoretical, smelling salts, fire extinguishing, rubber accelerators, chemical, explosives, baking powder, glues, cosmetics, soap, wine accelerator.
Ammonium celylsulphate	Flux for soldering.
Ammonium chloride or - sal ammoniac NH_4Cl	Paint and varnish, soldering flux, electrolyte in dry cells, fertilizer, textile printing, medicine, reactant, gelantizing agent, fireproofing, insecticide, soap, reagent, adhesives, chemical, coal products, iron cements, cosmetics, dry cleaning, lubricant, metallurgical, milling, paper, petroleum, refrigeration, stone, textile, water and sanitation, adhesives and glue, ceramic, disinfectant, dye, explosives and matches, food, rubber.
Ammonium chloroacetate	Protective agent for wood.
Ammonium chrome alum $(\text{NH}_4)_2\text{SO}_4 \cdot \text{Cr}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$	Mordanting and printing operations, manufacture of some inks.
Ammonium citrate $(\text{NH}_4)_2\text{HC}_6\text{H}_5\text{O}_7$	Rustproofing, cotton printing, plasticizer.

APPENDIX I (Con.)

Name	Uses
Ammonium dibutyl-naphthalene-sulfonate	Solvent, washing compounds, dyeing, finishing textiles.
Ammonium dichromate or - ammonium bichromate $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$	Pyrotechnics, antifreeze, reagent in making catalysts, purifying agent, etching agent, sensitizer, mordant.
Ammonium diorthoanisylphosphate	New medical.
Ammonium fluoride NH_4F	Antiseptic and preservative, etching agent for glass, treatment of soil, sterilizer, catalyst, moth repellant, wood preservative, carrotting furs.
Ammonium fluotitanate	Dyeing.
Ammonium glycerphosphate	Medicine.
Ammonium hydrate or - ammonium hydroxide NH_4OH	Household ammonia.
Ammonium hydrosulfide	Commercial product, denitrate nitro-cellulose product, sulfide finishes.
Ammonium hypochlorite	Reagent (chemical), disinfectant.
Ammonium hypophosphite $\text{NH}_4\text{H}_2\text{PO}_2$	Medicine, reducing agent.
Ammonium iodine NH_4I	Medicine, photography.
Ammonium lactate $\text{NH}_4\text{O}_2\text{CCHOHCH}_3$	Electroplating, leather tanning and finishing, absorbent, chemical, plating nickel or zinc.
Ammonium laurate $\text{NH}_4\text{O}_2\text{CC}_{11}\text{H}_{23}$	Cosmetic products, emulsifying agent.
Ammonium laurylsulfonate	Emulsifying agent.
Ammonium linoleate $\text{NH}_4\text{O}_2\text{CC}_{17}\text{H}_{31}$	Cosmetic products, emulsifying agent.
Ammonium molybdate $(\text{NH}_4)_2\text{MoO}_4$ (hydrated form = $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$)	Metallic molybdenum, pigments, photography.
Ammonium naphthenate	Coagulant, waterproofing agent, catalyst.
Ammonium nitrate NH_4NO_3	Fertilizers, freezing mixtures, explosives.

APPENDIX I (Con.)

Name	Uses
Ammonium nitrate limestone or - ammonium nitrate dolomite, lime- ammonia-nitrogen (a mixed product of ammonium nitrate)	Fertilizers, freezing mixtures, explosives.
Ammonium octodecylsulphonate	Emulsifying agent.
Ammonium oleate $\text{NH}_4\text{O}_2\text{C}(\text{CH}_2)_7\text{CH}:\text{CH}(\text{CH}_2)_7\text{CH}_3$	Cosmetic agent, emulsifying agent, dry cleaning agent, lubricant, rust preven- tive, insecticide.
Ammonium orthocyanobenzamide	Starting point in making metal phthal- ocyanin pigments with aminosulphonic acids and metal salts.
Ammonium orthocyanobenzoate	Do.
Ammonium oxalate $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$	Special explosives, removal of corrosion from metals, finishes and dressings, soap.
Ammonium phosphomolybdate	Paint and varnish, dye, reagent.
Ammonium phthalamate	Starting point in paint and varnishes.
Ammonium pentaborate $\text{NH}_4\text{B}_5\text{O}_8 \cdot 4\text{H}_2\text{O}$	Medicine, fire-retarding agents, condenser electrolytes.
Ammonium perchlorate NH_4ClO_4	Oxidizing agent in explosives and pyro- technics.
Ammonium persulfate $(\text{NH}_4)_2\text{S}_2\text{O}_8$	Manufacture of potassium persulfate, oxidizing copper, bleaching oils, dyes, batteries, foods, bleaches.
Ammonium phosphate or - (general term) monoammonium phosphate, primary ammonium phosphate, monobasic ammonium phosphate, ammonium phosphate-hemibasic $(\text{NH}_4)\text{H}_2\text{PO}_4$	Medicine, fireproofing textiles, ferti- lizers, nutrient, reagent, soldering flux, green pigment.
Ammonium polysulfide $(\text{NH}_4)_2\text{S}$	Denitrate nitrocellulose products, sulfide finishes, dyes, insecticide, dehairing hides.
Ammonium-potassium borofluoride	Fuels.
Ammonium propionate	Lubricant, dressing and finishing leathers, fuels, soaps.

APPENDIX I (Con.)

Name	Uses
Ammonium salicylate	Medicine, preservative, germicide, reagent in making synthetics as resins.
Ammonium selenate	Reagent in testing for alkaloids, codeine, red glass, mothproofing.
Ammonium selenite	Mothproofing.
Ammonium selenocyanate	Sterilizer, parasiticide.
Ammonium silicofluoride or ammonium fluosilicate $(\text{NH}_4)\text{SiF}_6$	Medicine, mild neutralizing agent, setting of cements, fertilizers, mothproofing.
Ammonium silicomolybdate	Dye, paint, and varnish.
Ammonium silicotungstate	Do.
Ammonium soaps (generally refers to ammonium oleate)	Manufacture of toilet preparations.
Ammonium stearate $\text{NH}_4\text{O}_2\text{C}(\text{CH}_2)_{16}\text{CH}_3$	Emulsifying agent, waterproofing agent in concrete, preparation of special stearates.
Ammonium succinate	Reagent in making succinamide.
Ammonium sulfamate or ammonium amidosulfonate $\text{NH}_4\text{SO}_3\text{NH}_2$	Flameproofing textiles, paper and wood; herbicide.
Ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$	Fertilizer, flux in soldering, cosmetic ingredient, fertilizer, fireproofing, glass, soap, treating water, activating agent, nitrogenous food, precipitant, reagent, dye, batteries, baking powders, candle wicks, neutralizing hides.
Ammonium sulfide $(\text{NH}_4)_2\text{S}$	Sulfide finishes on metals, in denitrate nitrocellulose products.
Ammonium sulfocyanate	Reagent, starting point, fulminating agents, dyes, explosives, fertilizer, insecticide, photography.
Ammoniated superphosphates	Fertilizers.
Ammonium telluride	Catalyst, reagent.
Ammonium thiocyanate or - ammonium sulfocyanide, ammonium sulfocyanate, ammonium rhodanide, NH_4SCN	Thiourea, photography, dyeing, and printing textiles, insecticides, lubricants, corrosive agent, swelling agent.
Ammonium thioglycolate $\text{CH}_2\text{SHCOONH}_4$	Reagent for permanent hair waving by the cold process.

APPENDIX I (Con.)

Name	Uses
Ammonium thiosulfate or - ammonium hyposulfite $(\text{NH}_4)_2\text{S}_2\text{O}_3$	Reducing agent, photographic grade.
Ammonium-tin carbonate	Delustring agent-textiles.
Ammonium-tin citrate	Do.
Ammonium-tin oxalate	Do.
Ammonium-tin tartrate	Do.
Ammonium-titanium carbonate	Do.
Ammonium-titanium citrate	Do.
Ammonium-titanium oxalate	Do.
Ammonium-titanium tartrate	Do.
Ammonium uranate	Reagent in removing albuminous substances from therapeutic sera and other liquids.
Ammonium vanadate	Reagent, catalyst, starting point, dye, ink, drier for linseed oil, mordant.
Diammonium phosphate or - secondary ammonium phosphate, dibasic ammonium phosphate $(\text{NH}_4)_2\text{HPO}_4$	Medicinals, textiles, fire-retarding agent, fertilizer material.
Diethanolamine $(\text{HOC}_2\text{H}_5)_2\text{NH}$	Dry cleaning, solvent for oils and fats, dyes, pharmaceutical, soaps.
Diethylamine $(\text{C}_2\text{H}_5)_2\text{NH}$	Synthetic organic chemistry, catalyst, reagent, dye.
Dimethylamine $(\text{CH}_3)_2\text{NH}$	Organic synthesis, rubber accelerator, agricultural, dye, starting point.
Ethanolamine or - monoethanolamine $\text{H}_2\text{NCH}_2\text{CH}_2\text{OH}$	Dry cleaning, solvent for oils and fats, dyes, pharmaceuticals, soaps, absorbent, emulsifying agent.
Ethylamine or - monoethylamine $\text{C}_2\text{H}_5\text{NH}_2$	Dye intermediates.
Guanidine $\text{HNC}(\text{NH}_2)_2$	Rubber accelerator, reagent, dye, fertilizers, fire extinguishing.
Methylamine or - monomethylamine CH_3NH_2	Limited in its use because the higher boiling primary amines, such as amylamine, are easier to handle.

APPENDIX I (Con.)

Name	Uses
Nitric acid HNO_3	Oxidizing agent, explosives, etching, photoengraving, ceramics, solvent, reagent, starting point, dye, metallurgical, rubber substitutes.
Sesquicarbonate (an NF grade) or - ammonium bicarbonate NH_4HCO_3 ammonium carbamate $\text{NH}_4\text{NH}_2\text{CO}_2$	Smelling salts, rubber accelerators. Fertilizer, starting point for various carbamates.
Triammonium phosphate $(\text{NH}_4)_3\text{PO}_4$	Relatively unimportant - on exposure to air gives off ammonia to form the diammonium compound.
Triethanolamine $(\text{HOC}_2\text{H}_5)_3\text{N}$	Soaps, emulsifying agent, absorption of acid gases.
Triethylamine $(\text{C}_2\text{H}_5)_3\text{N}$	Manufacture of quarternary ammonium compounds.
Thiourea $\text{CS}(\text{NH}_2)_2$	Synthesis of organic sulfur compounds.
Trimethylamine $(\text{CH}_3)_3\text{N}$	Synthetic organic reactions.
Urea or - carbamide $\text{CO}(\text{NH}_2)_2$	Organic synthesis, solubilizing agents, fertilizer ingredients, plastics, stock food.

APPENDIX II

Plant nutrients removed by crops

Compiled by A. C. Burr

No.	Crop	Portion	Yield per acre	Nutrient removed			Reference
				N	P ₂ O ₅	K ₂ O	
1	Alfalfa	Hay	1.97 tons	-	4.8 lb./ton	-	1
2	do.	do.	3 tons	47 lb./ton	12 lb./ton	45 lb./ton	3,5
3	do.	do.	4 tons	48 lb./ton	-	-	4,6
4	do.	do.	10 tons	-	-	10 lb./ton	2
5	Apples	Fruit	300 bu.	0.057 lb./bu.	-	-	6
6	do.	do.	400 bu.	0.050 lb./bu.	0.018 lb./bu.	0.075 lb./bu.	3
7	Barley	Grain	30 bu.	0.90 lb./bu.	-	-	6
8	do.	do.	40 bu.	0.88 lb./bu.	-	-	4
9	do.	do.	40 bu.	0.88 lb./bu.	0.38 lb./bu.	0.25 lb./bu.	3
10	do.	Straw	0.8 tons	11 lb./ton	-	-	6
11	do.	do.	1.0 tons	12 lb./ton	-	-	4
12	do.	do.	1.0 tons	15 lb./ton	5.0 lb./ton	30 lb./ton	3
13	Beets	Roots	12.5 tons	-	-	10 lb./ton	2
14	Bluegrass	Hay	1 ton	27 lb./ton	-	-	6
15	Cabbage	Heads	10 tons	6 lb./ton	-	-	6
16	do.	All	15 tons	6.7 lb./ton	1.7 lb./ton	6.7 lb./ton	3
17	do.	do.	15 tons	7.0 lb./ton	-	-	4
18	Carrots	Roots	5 tons	-	-	10 lb./ton	2
19	Celery	All	350 crates	0.23 lb./crate	0.19 lb./crate	0.67 lb./crate	3
20	Clover	Hay	2 tons	41 lb./ton	-	-	6
21	Clover (alsike)	do.	2 tons	41 lb./ton	-	-	4
22	Clover (red)	do.	1.13 tons	-	3.9 lb./ton	-	1
23	do.	do.	2 tons	42 lb./ton	-	-	4
24	do.	do.	2 tons	40 lb./ton	10 lb./ton	35 lb./ton	3
25	do.	do.	6 tons	-	-	10 lb./ton	2
26	Clover (sweet)	do.	5 tons	37 lb./ton	9 lb./ton	33 lb./ton	3
27	Corn	Grain	25 bu.	-	-	0.22 lb./bu.	2
28	do.	do.	29 bu.	-	0.21 lb./bu.	-	1
29	do.	do.	60 bu.	0.95 lb./bu.	0.38 lb./bu.	0.25 lb./bu.	3,5
30	do.	Ears	60 bu.	0.95 lb./bu.	-	-	6
31	do.	Cobs	0.125 tons	-	-	8.8 lb./ton	2
32	do.	do.	0.45 tons	6.7 lb./ton	-	-	4
33	do.	Stover	0.75 tons	-	-	28 lb./ton	2
34	do.	do.	1.35 tons	-	2.7 lb./ton	-	1
35	do.	do.	2 tons	19 lb./ton	6 lb./ton	28 lb./ton	3
36	do.	do.	1.75 tons	19 lb./ton	-	-	4
37	do.	do.	2 tons	18 lb./ton	-	-	6
38	do.	Silage	12 tons	6.8 lb./ton	-	-	4,6
39	Cotton	Lint and seed	0.25 tons	152 lb./ton	72 lb./ton	56 lb./ton	5
40	do.	do.	0.4 tons	-	9.3 lb./ton	-	1
41	do.	do.	0.75 tons	51 lb./ton	24 lb./ton	19 lb./ton	3
42	do.	do.	0.75 tons	53 lb./ton	-	-	4
43	do.	do.	0.75 tons	53 lb./ton	-	-	6
44	do.	Stalk, etc.	0.7 tons	-	2.4 lb./ton	-	1
45	do.	do.	0.75 tons	36 lb./ton	9.3 lb./ton	48 lb./ton	3
46	do.	do.	1 ton	28 lb./ton	-	-	4
47	do.	do.	1.4 tons	25 lb./ton	-	-	6
48	Cowpeas	Hay	2 tons	62 lb./ton	-	-	4
49	do.	All	2 tons	62 lb./ton	12 lb./ton	45 lb./ton	3
50	do.	Hay	2 tons	50 lb./ton	-	-	6
51	do.	Grain	15 bu.	2.3 lb./bu.	-	-	6
52	Grapes	Fruit	4 tons	2.5 lb./ton	1.5 lb./ton	5 lb./ton	3
53	Lespedeza	Hay	3 tons	43 lb./ton	10 lb./ton	23 lb./ton	3,5
54	Mangles	Roots	40 tons	4.4 lb./ton	-	-	6
55	Oats	Grain	25 bu.	-	-	0.18 lb./bu.	2
56	do.	do.	32 bu.	-	0.1 lb./bu.	-	1
57	do.	do.	50 bu.	0.64 lb./bu.	-	-	6
58	do.	do.	50 bu.	0.70 lb./bu.	-	-	4
59	do.	do.	50 bu.	0.70 lb./bu.	0.3 lb./bu.	0.2 lb./bu.	3
60	do.	Straw	0.62 tons	-	-	25 lb./ton	2
61	do.	do.	0.6 tons	-	2.0 lb./ton	-	1
62	do.	do.	1.0 tons	12 lb./ton	-	-	6
63	do.	do.	1.25 tons	12 lb./ton	-	-	4
64	do.	do.	1.25 tons	12 lb./ton	4.0 lb./ton	28 lb./ton	3

APPENDIX II (Con.)

No.	Crop	Portion	Yield per acre	Nutrient removed			Reference
				N	P ₂ O ₅	K ₂ O	
65	Onions	Bulb	500 bu.	0.12 lb./bu.	-	-	4
66	do.	do.	600 bu.	0.15 lb./bu.	-	-	6
67	Oranges	Fruit	600 boxes	0.11 lb./box	0.04 lb./box	0.18 lb./box	3
68	Pea beans	Grain	30 bu.	2.4 lb./bu.	0.77 lb./bu.	0.80 lb./bu.	3
69	Peaches	Fruit	500 bu.	0.06 lb./bu.	0.03 lb./bu.	0.11 lb./bu.	3,5
70	do.	do.	500 bu.	0.06 lb./bu.	-	-	6
71	do.	Nuts	1 ton	70 lb./ton	-	-	6
72	do.	do.	1 ton	60 lb./ton	10 lb./ton	10 lb./ton	3
73	do.	Vines	2 tons	42 lb./ton	-	-	6
74	do.	do.	3 tons	8.3 lb./ton	1.7 lb./ton	13.3 lb./ton	3
75	Potatoes	Tuber	126 bu.	-	0.032 lb./bu.	-	1
76	do.	do.	150 bu.	-	-	0.3 lb./bu.	2
77	do.	do.	200 bu.	0.22 lb./bu.	-	-	4
78	do.	do.	300 bu.	0.21 lb./bu.	-	-	6
79	do.	do.	300 bu.	0.22 lb./bu.	0.083 lb./bu.	0.38 lb./bu.	3,5
80	Rice	Grain	49 bu.	-	0.14 lb./bu.	-	1
81	do.	Straw	1.4 tons	-	2.3 lb./ton	-	1
82	Rye	Grain	20 bu.	-	-	0.33 lb./bu.	2
83	do.	do.	25 bu.	1.1 lb./bu.	-	-	4
84	do.	do.	30 bu.	1.1 lb./bu.	-	-	6
85	do.	Straw	1 ton	-	-	17 lb./ton	2
86	do.	do.	1.25 tons	9.6 lb./ton	-	-	4
87	do.	do.	1.5 tons	9.3 lb./ton	-	-	6
88	Soy beans	Grain	18.6 bu.	-	0.42 lb./bu.	-	1
89	do.	do.	20 bu.	3.5 lb./bu.	-	-	6
90	do.	do.	25 bu.	4.4 lb./bu.	1.4 lb./bu.	1.6 lb./bu.	3,5
91	do.	Straw	1.45 tons	-	2.9 lb./ton	-	1
92	do.	do.	2 tons	51 lb./ton	-	-	6
93	do.	do.	1.25 tons	12 lb./ton	4.0 lb./ton	16 lb./ton	3
94	Spinach	Tops	500 bu.	0.088 lb./bu.	-	-	6
95	do.	All	1000 bu.	0.09 lb./bu.	0.03 lb./bu.	0.045 lb./bu.	6
96	Sugar beets	Roots	12.6 tons	-	0.44 lb./bu.	-	1
97	do.	do.	15 tons	3.7 lb./ton	1.5 lb./ton	3.5 lb./ton	3,5
98	do.	do.	15 tons	5.2 lb./ton	-	-	4
99	do.	do.	15 tons	5.1 lb./ton	-	-	6
100	Sugar cane	Stalks, stripped	15 tons	-	-	1.2 lb./ton	2
101	do.	Leaves and tops	10 tons	-	-	1.8 lb./ton	2
102	Sweet potatoes	Tuber	200 bu.	-	-	0.27 lb./bu.	2
103	do.	do.	200 bu.	0.18 lb./bu.	-	-	4
104	do.	do.	300 bu.	0.13 lb./bu.	-	-	6
105	do.	do.	300 bu.	0.15 lb./bu.	0.05 lb./bu.	0.25 lb./bu.	3
106	Timothy	Hay	1.5 tons	27 lb./ton	10 lb./ton	30 lb./ton	3
107	do.	do.	1.5 tons	20 lb./ton	-	-	6
108	do.	do.	2 tons	20 lb./ton	-	-	4
109	Tobacco	Leaves	0.47 tons	-	4.7 lb./ton	-	1
110	do.	do.	0.5 tons	-	-	115 lb./ton	2
111	do.	do.	0.5 tons	88 lb./ton	-	-	6
112	do.	do.	0.75 tons	73 lb./ton	13 lb./ton	107 lb./ton	3,5
113	do.	do.	0.75 tons	55 lb./ton	-	-	4
114	do.	Stalks	0.22 tons	67 lb./ton	-	-	6
115	do.	do.	0.62 tons	42 lb./ton	-	-	4
116	Tomatoes	Fruit	8 tons	4 lb./ton	-	-	6
117	do.	do.	10 tons	6 lb./ton	2 lb./ton	8 lb./ton	3,5
118	Turnip	Roots	360 bu.	-	-	0.25 lb./bu.	2
119	do.	do.	400 bu.	0.13 lb./bu.	-	-	6
120	Wheat	Grain	14.6 bu.	-	0.21 lb./bu.	-	1
121	do.	do.	25 bu.	-	-	0.24 lb./bu.	2
122	do.	do.	30 bu.	1.2 lb./bu.	0.53 lb./bu.	0.3 lb./bu.	3,5
123	do.	do.	30 bu.	1.2 lb./bu.	-	-	4
124	do.	Straw	0.9 tons	-	1.4 lb./ton	-	1
125	do.	do.	1.25 tons	-	-	12 lb./ton	2
126	do.	do.	1.25 tons	12 lb./ton	3.2 lb./ton	17 lb./ton	3

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